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PRELIMINARY DESIGN OF PROPULSION SYSTEM FOR V/STOL RESEARCH AND TECHNOLOGY AIRCRAFT

Final Report

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16. Abstract

The V/STOL Research and Technology Aircraft (RTA) propulsion system consists of two lift/cruise, variable-pitch turbofan engines, one turboshaft engine, and one variable-pitch lift fan—all connected with shafting through a combiner gearbox. Design effort was limited to components of the lift/cruise engines, turboshaft engine modifications, lift fan assembly, and propulsion system performance generation. The uninstalled total net thrust with all engines and fans operating at intermediate power is 37,114 pounds. Uninstalled system total net thrust is 27,102 pounds when one lift/cruise engine is inoperative. A lift/cruise engine for a fixed nacelle installation weighs 2310 pounds. A lift/cruise engine for a tilt nacelle installation weighs 2583 pounds. The turboshaft engine and lift fan assembly weigh 1135 and 913 pounds, respectively. Components have lives above the 500 hours of the RTA duty cycle. The L/C engine used in a fixed nacelle has the cross shaft forward of the reduction gear whereas the cross shaft is aft of the reduction gear in a tilt nacelle L/C engine. The lift/cruise gearbox contains components and technologies from other DDA engines. The variable-pitch lift/cruise and lift fan rotors designed by Hamilton Standard are common. The rotor has a 62-inch diameter and contains 22 composite blades that have a hub/tip ratio of 0.454. The blade pitch change mechanism contains hydraulic and mechanical redundancy. The lift fan assembly is completely self-contained including oil cooling in 10 exit vanes.

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PREFACE

The inclusion of SI Units in this Final Report has been waived under the authority of NPD 2220:4, subparagraph 5.d. An SI Units conversion table is supplied in Appendix A.

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SUMMARY

The V/STOL Research and Technology Aircraft (RTA) propulsion system consists of two lift/cruise (L/C), variable-pitch turbofan engines, one turboshaft engine, and one variable-pitch lift fan—all connected with shafting through a combiner gearbox. Detroit Diesel Allison (DDA) Model PD370-30 defines the propulsion system with separate jet turbofan engines. PD370-32 describes the system using confluent flow turbofan engines. Lift/cruise turbofan engines are designated PD370-25 with a suffix to identify aircraft installation. The L/C engine is a modified Allison XT701-AD-700 integrated with a Hamilton Standard variable-pitch fan in a conventional front fan arrangement.

Preliminary design effort was limited to components of the lift/cruise engines, turboshaft engine modifications, lift fan assembly, and propulsion system performance generation. The system design point was the VTOL mode of operation at sea level static, 90°F day conditions, and the engines operating at intermediate power.

The total three-engine, three-fan (3E-3F) intermediate power thrust is not used to size the aircraft because of a requirement for a thrust-to-weight ratio of 1.03 during a one-engine-inoperative (OEI) vertical takeoff or landing. Thus, the sizing condition is for one of the turbofan engines inoperative.

Total thrust available with engines at intermediate power on a 90°F day from three engines operating and two engines operating (one lift/cruise turbofan out) is summarized as follows:

	Thrust (lb)	
	3E-3F	2E-3F
Uninstalled	37,114	27,102
Installed with McDonnell factors	33,324	24,279
Installed with Boeing factors	35,518	25,780

PD370-25A is the lift/cruise engine designed for the fixed nacelle application. The cross shaft is forward of the reduction gear in this engine. PD370-25E is the lift/cruise engine designed for the tilt nacelle application. It has the cross shaft aft of the reduction gear.

The weights of the propulsion system components are as follows:

PD370-25A	2310 lb
PD370-25E	2583 lb
Center engine	1135 lb
Lift fan assembly	913 lb

Propulsion system components have design lives greater than the 500 hours of the RTA duty cycle. The lift/cruise gearbox uses reduction gears and safety coupling technology from the Allison T56 engine. These components not only add reliability to the propulsion system but also decrease the development time.

During a propulsion system safety analysis, the following real or potential undesired events were identified. These events could, without control to preclude occurrence, result in a Category IV safety hazard:

- Noncontainment of high-energy pieces
- Fire external to the engine
- Loss of fan rotation
- Loss of engine/nacelle
- Toxic fumes
- Torsional instability
- Simultaneous multiple-engine shutdown

An assessment of the 78 components and conditions that could contribute to the preceding real or potential undesired events revealed that adequate preliminary design considerations have been applied toward precluding failure in five of the seven undesired events. Torsional instability and simultaneous multiple-engine shutdown would require particular attention in a final design to preclude occurrence.

DDA has prepared a computer card deck to calculate propulsion system steady-state performance. Performance can be calculated for either vertical or conventional flight. The card deck will also calculate either installed or uninstalled performance. The user can determine system performance at the following optional modes:

- Pitch and roll attitude control
- All engines operating
- One engine inoperative (either a turbofan or the turboshaft)
- Water-alcohol injection
- Contingency power level above intermediate
- Mixed- or separate-flow turbofan engines

The lift fan is a variable-pitch, 62-inch diameter, low-pressure-ratio fan. The fan is mounted in the nose of the aircraft fuselage to provide lift thrust during V/STOL operation. The variable-pitch rotor blade system provides for a wide range of fan performance by controlling the blade angle of attack which leads to a change in airflow and pressure ratio. The blade pitch can be changed during fan operation, providing an increased/decreased lift for aircraft control.

The lift fan has four major assemblies:

- Rotor
- Gear reduction assembly
- Fan case
- Pitch control system

The rotor assembly consists of 22 blades, attaching and rotating hardware and the hydraulic pitch change mechanism. The variable-pitch blades are of a spar-shell construction, using a lightweight composite material, boron/aluminum, for the airfoil shells and a titanium spar to transfer the air loads into the rotor disk and pitch change system. The rotor system is common to the lift and lift/cruise fans.

A bevel gearset, a drive shaft, and bearing supports in the gear reduction assembly provide the power transfer from the aircraft shaft drive to the rotor.

The lift fan case is a welded titanium structure with an outer shell which is the fan duct and provides a fan assembly mounting point, a hub to support the rotor and gear reduction assembly, and 28 stator vanes for aerodynamic performance and structural support for the hub. Ten fan case stators are used as an oil cooler for the lube oil. The heat load transferred through the stators to the fan through airflow will cause a temperature rise of less than 1.0°F.

The rotor pitch control system is composed of two redundant electro-hydraulic control modules—Beta regulators—which accept an electrical input command and proportionally control the hydraulic oil flow to the pitch change actuator. Each Beta regulator contains a system shutoff valve, a control valve, a bypass valve, and an indicator. The control system also includes a triply-redundant linear variable differential transformer (LVDT) mounted on the rotor to provide a feedback of the actuator position.

The lift/cruise variable-pitch fan uses a 62-inch diameter rotor assembly that is interchangeable with the lift fan rotor. The rotor interfaces with the L/C gearbox and fan frame, which contains the 10 exit struts and 87 guide vanes. Pitch control systems are also interchangeable between the lift and lift/cruise fans.

A preliminary hazard analysis was conducted for the lift fan assembly. Three hazardous consequences were found:

- Unable to change pitch
- Loss of lift fan function
- Aircraft damage

Adequate preliminary design considerations have been applied toward precluding these hazards.

INTRODUCTION

Detroit Diesel Allison (DDA) Division of General Motors Corporation provided engineering support to aircraft company studies of V/STOL aircraft during 1975. These studies established that the Allison XT701-AD-700 (XT701) turboshaft engine was a viable candidate for use in a research and technology aircraft program. DDA work under NASA Contract NAS3-20034 in 1976 further defined a shaft-driven lift/cruise fan propulsion system for the V/STOL Research and Technology Aircraft (RTA). Concurrently, Hamilton Standard (HS) Division of United Technologies completed a variable-pitch lift/cruise fan system study and further defined fan system components and interfaces under NASA Contracts NAS3-19414 and NAS3-20033.

The contract work being reported is an extension of the aforementioned studies and addresses the preliminary design of RTA propulsion system components. DDA subcontracted the preliminary design of the variable-pitch lift fan assembly and the variable-pitch lift/cruise fan rotor assembly to Hamilton Standard. HS's design effort is integrated with DDA's design effort throughout the report.

The system shown in Figure 1 consists of two lift/cruise (L/C) turbofan engines, one turboshaft engine, and one lift fan—all connected with shafting through a combiner gearbox. The design work under this contract was limited to components of the lift/cruise turbofan engine, turboshaft engine, and lift fan assembly. DDA Model PD370-30 defines the system with separate jet turbofan engines. PD370-32 describes the system using confluent-flow turbofan engines. Lift/cruise turbofan engines are designated PD370-25, with a suffix identifying aircraft installation. The L/C engine is a modified XT701 integrated with an HS variable-pitch fan in a conventional front fan arrangement. The center engine is a standard XT701. The lift fan assembly and lift/cruise variable-pitch fan rotors are common hardware. The lift fan is mounted to produce lift in the vertical mode and is disconnected during the horizontal flight mode.

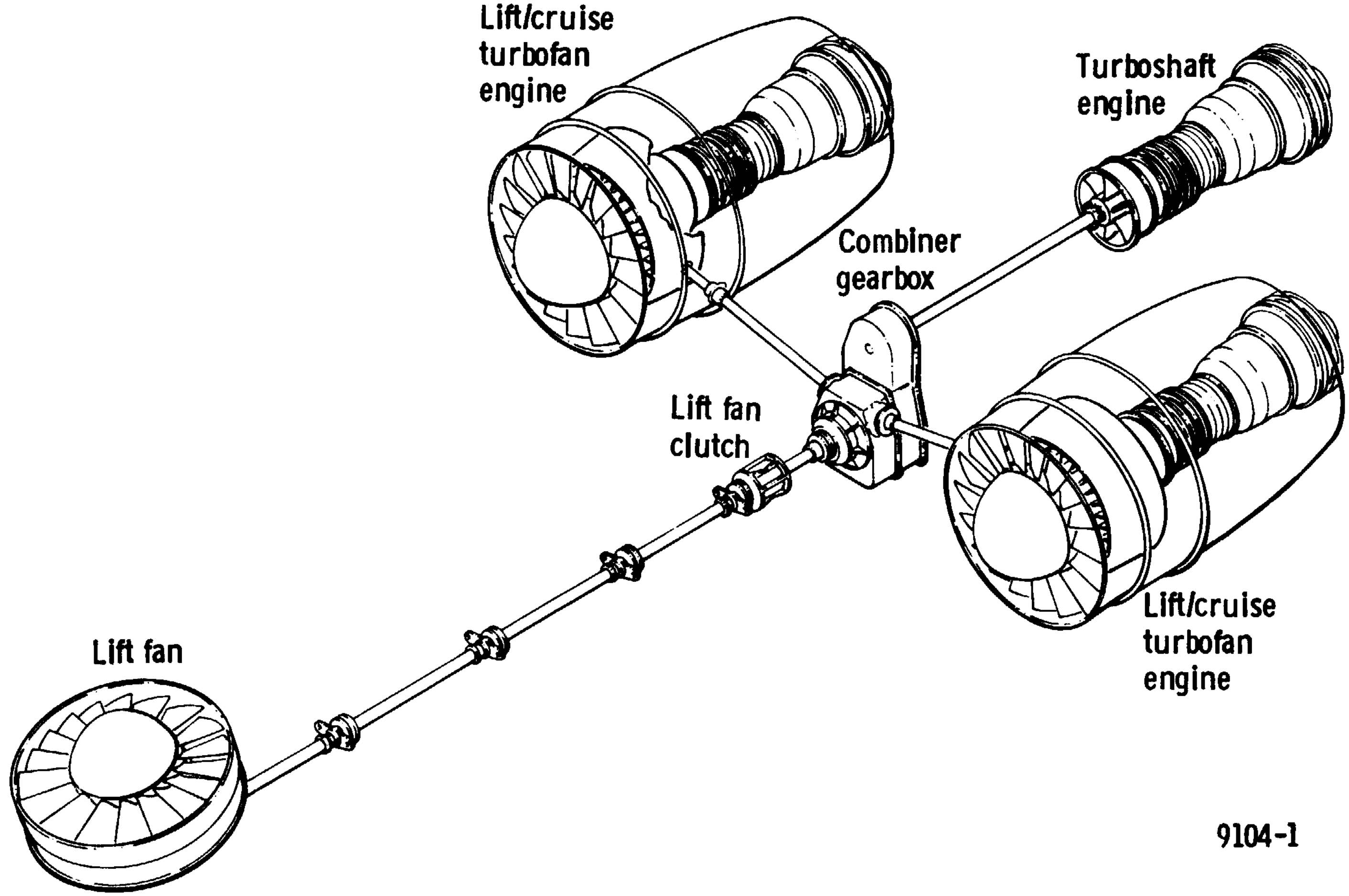


Figure 1. V/STOL Research and Technology Aircraft propulsion system.

PROPULSION SYSTEM DEFINITION

GENERAL DESCRIPTION

The shaft-driven lift/cruise fan propulsion system (Figure 1) for the V/STOL RTA consists of two L/C turbofan engines, one turboshaft engine, and one lift fan connected by shafting through a combiner gearbox. A disengaging clutch permits the disconnection of the lift fan during cruise operations.

Vertical takeoff or landing operation with this system is achieved by driving all three fans and vectoring the fan thrust downward. The lift fan is mounted so that it normally produces lift, and the lift/cruise fans incorporate special thrust vectoring. Two lift/cruise vectoring schemes are considered:

1. The lift cruise engine is fixed in the horizontal position and there is an adjustable gas deflector at the engine exhaust.
2. The lift cruise engine is rotated about the radial drive center line to produce lift.

For normal, horizontal flight, only the thrust produced at the lift/cruise fans is utilized. The lift fan and center engine are disconnected.

A short discussion of the overall system is appropriate even though all the components are not included in this design effort.

Each L/C engine transmits its power directly to the cross shafting system through an overrunning clutch. This allows for loss or shutdown of one engine without the loss of system power that would occur if the two "live" engines had to drive the "dead" power turbine.

The shafting and combiner box system allows for transfer of power from one side of the airframe to the other as would be required to compensate for roll correction. The system also has the capability of effecting pitch corrections.

The lift fan clutch makes it possible to disconnect the lift fan in horizontal flight.

Because the fans operate at a lower speed than the power turbines, a reduction gear is associated with each fan—a star gearset for the lift/cruise fans and spiral bevel gears for the lift fan.

LIFT FAN ASSEMBLY

The V/STOL RTA lift fan is a variable-pitch, 62-inch diameter, low-pressure-ratio fan. The lift fan is mounted in the nose of the aircraft fuselage to provide lift thrust during V/STOL operation. The variable-pitch rotor blade system provides for a wide range of fan performance by controlling the blade angle of attack which leads to a change in airflow and pressure ratio. The blade pitch can be changed during fan operation, providing an increased/decreased lift for aircraft control. The following are the fan characteristics:

Thrust, lb	
Normal takeoff	9,600
Max control	11,600
Power required, hp	
Normal takeoff	6,400
Max control	8,600
Blade angle range ($\Delta\beta$) (from design point), degrees	+10 to -40
Surge margin, %	
Normal	27
Max control	17
Weight, lb	
Lift fan	913
Lift/cruise fan	324

The lift fan has four major assemblies:

- Rotor
- Gear reduction assembly
- Fan case
- Pitch control system

The rotor assembly consists of the blades, attaching and rotating hardware, and the hydraulic pitch change mechanism (Figure 2). The design operating speed of 3543 rpm was selected to attain a blade tip speed that would provide a peak operating efficiency.

The variable-pitch blades are of a spar-shell construction, using a lightweight composite material—boron/aluminum—for the airfoil shells and a titanium spar to transfer the air loads into the rotor disk and pitch change system. The composite blade design has been extensively tested during its development. Composite test blades have demonstrated an FOD tolerance comparable with today's solid titanium blades.

The blade retention and rotor disk absorbs the centrifugal, thrust, and vibratory loads of the blades. These structural members are designed to a "lightweight system" philosophy but provide an adequate stress safety margin.

The retention bearing is lubricated by a high-viscosity grease. Grease was selected for the RTA design because it offers the needed lubrication qualities with low development risk.

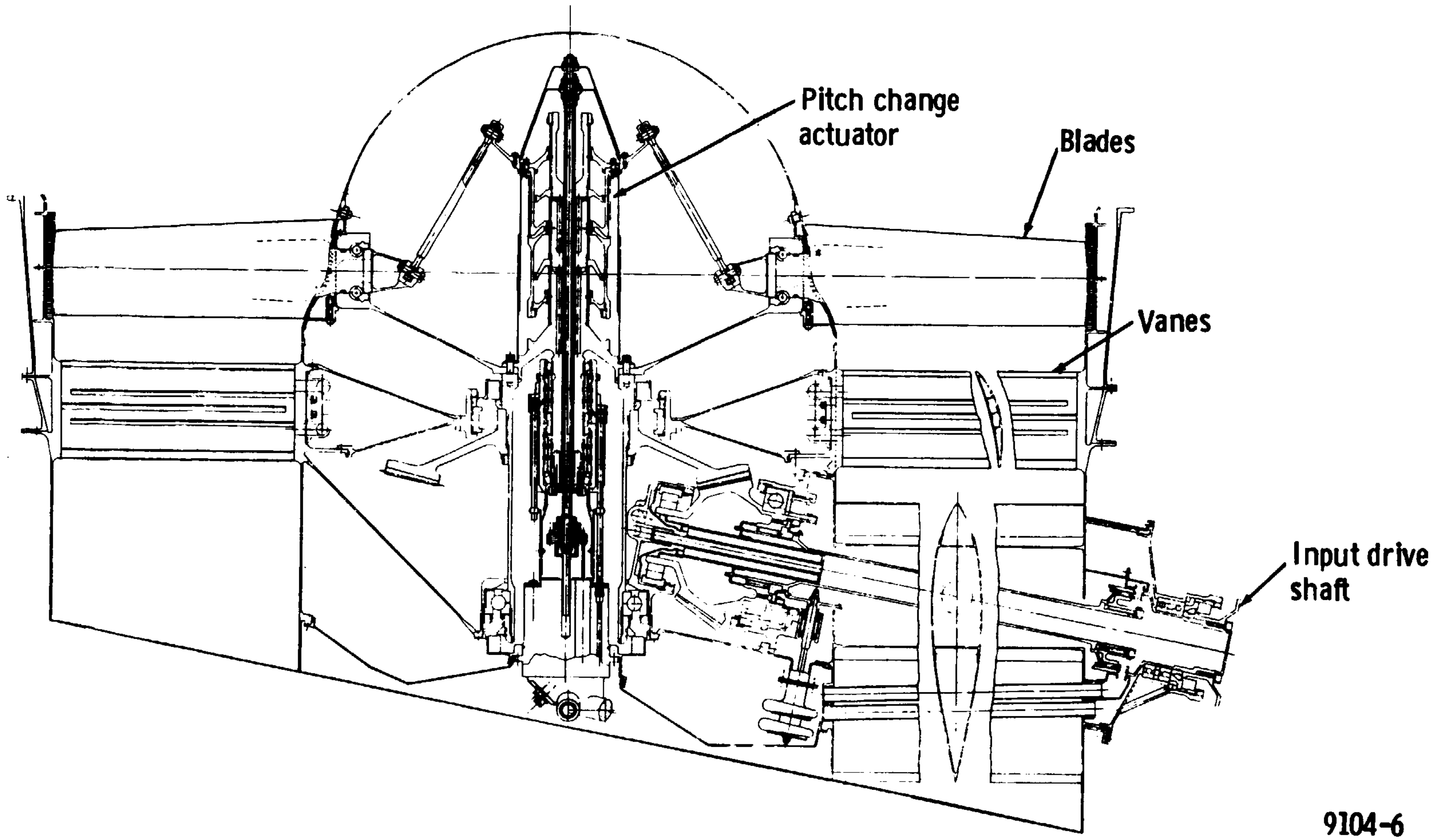


Figure 2. Lift fan assembly drawing.

The rotor pitch change actuator is mounted inside the rotating hub to provide a direct link with the blades. A stiff link connects the actuator and the blade trunnions. The actuator is powered by the aircraft hydraulic system. Hydraulic fluid from the aircraft hydraulic system passes through a stationary control module mounted on the airframe and is transferred to the rotating actuator by a "transfer bearing." This rotating fluid seal concept has been developed and used by Hamilton Standard in nearly all variable-pitch propeller and fan applications.

The lift fan gear reduction assembly accepts the input drive power from the aircraft shaft system and transmits it at the required speed and drive angle to power the rotor. A bevel gearset, drive shaft, and bearing supports provide the power transfer from the aircraft shaft drive system to the rotor. An integral lubrication system, which uses the stator vanes to cool the lubricant, is provided.

The lift fan case is a welded titanium structure with an outer shell which is the fan duct and provides a fan assembly mounting point, a hub to support the rotor and gear reduction assembly, and stator vanes for aerodynamic performance and structural support for the hub. The fan case design was sized by stiffness requirements to ensure that the natural frequency of the hub-stator-shell system was outside the excitation frequency of a once-per-revolution range of the rotor speed.

Ten of the 28 fan case stators are used as an oil cooler for the lube oil. The hollow stators are channeled to provide lube oil exposure to the stator internal surfaces. The heat load transferred through the stators to the fan through airflow will cause a temperature rise of less than 1.0°F.

The rotor pitch control system is composed of two redundant electro-hydraulic control modules—Beta regulators—which accept an electrical input command and proportionally control the hydraulic oil flow to the pitch change actuator. Each Beta regulator contains a system shutoff valve, a control valve (EHV), a bypass valve, and an indicator. The control system also includes a triply-redundant LVDT mounted on the rotor to provide a feedback of the actuator position (which is directly proportional to the blade angle).

The fan control system changes the blade pitch in response to a command signal from the propulsion control system. The blades are positioned in response to a required setting. The Beta regulators can shut down a hydraulic channel by command of the propulsion control system if a failure is detected. A system failure is detected through comparison of the two redundant active control systems with a model of the pitch change system in the propulsion computer. If a system is shut down, a bypass valve channels the flow of hydraulic oil between the two inactivated actuator chambers to allow movement of the actuator as controlled by the remaining system.

A bypass indicator provides a signal to the propulsion control system if a control channel is shut down.

LIFT/CRUISE ENGINE—FIXED NACELLE

A lift/cruise engine for the fixed nacelle application was designed with airframe guidance from McDonnell Douglas Corporation. An installation drawing depicting this effort is shown in Figure 3. This engine assembly has been designated DDA Model PD370-25A. The weight, center of gravity, and pertinent dimensions are shown in Figure 3. The lift/cruise engine is suitable for either left or right wing installation (the right side installation is shown).

The PD370-25A engine incorporates the following features:

- Forward engine mounts located aft of splitter
- Rear engine mount at turbine exhaust case
- MS3327-85 starter pad for airframer-supplied starter
- MS3327-5 accessory pad, HP driven—may be used as hydraulic pump drive
- HP-driven accessory pad for QAD-mounted CSD-driven alternator
- Cross drive output suitable for power transfer
- Doubly-redundant hydraulic Beta control system
- Triply-redundant electronic feedback from fan LVDT
- Electronic engine control to mate with fly-by-wire airframe control system
- Internal fan drive gearbox components that can be oriented for left or right side engine—cross drive output is 18% below horizontal center line

The power section for the engine is an Allison XT701 turboshaft. The fan is a 62-inch diameter Hamilton Standard variable pitch configuration. The fan disk, blade control system, etc, are the same as those described for the lift fan. The design point speed for the fan is 3543 rpm; because it is driven through a 3.33:1 reduction gear, this sets the power turbine speed at 11,810 rpm. The cross drive output speed is 11,810 rpm at the design point. Fan rotation is CCW viewed from the rear. Cross drive rotation is CCW looking into the pad. Power turbine rotation is CW viewed from the rear.

Thrust vectoring for VTOL operation would be accomplished by aircraft company-supplied nacelle components that deflect the exhaust of the lift/cruise engines.

LIFT/CRUISE ENGINE—TILT NACELLE

A lift/cruise engine for the tilt nacelle application was designed with airframe guidance from the Boeing Company. Figure 4 is an installation drawing depicting this effort. This engine assembly has been designated DDA Model PD370-25E. Its weight, center of gravity, and pertinent dimensions are shown in Figure 4. This lift/cruise engine is suitable for either left or right side installation (the right side installation is shown).

The PD370-25E engine incorporates the following features:

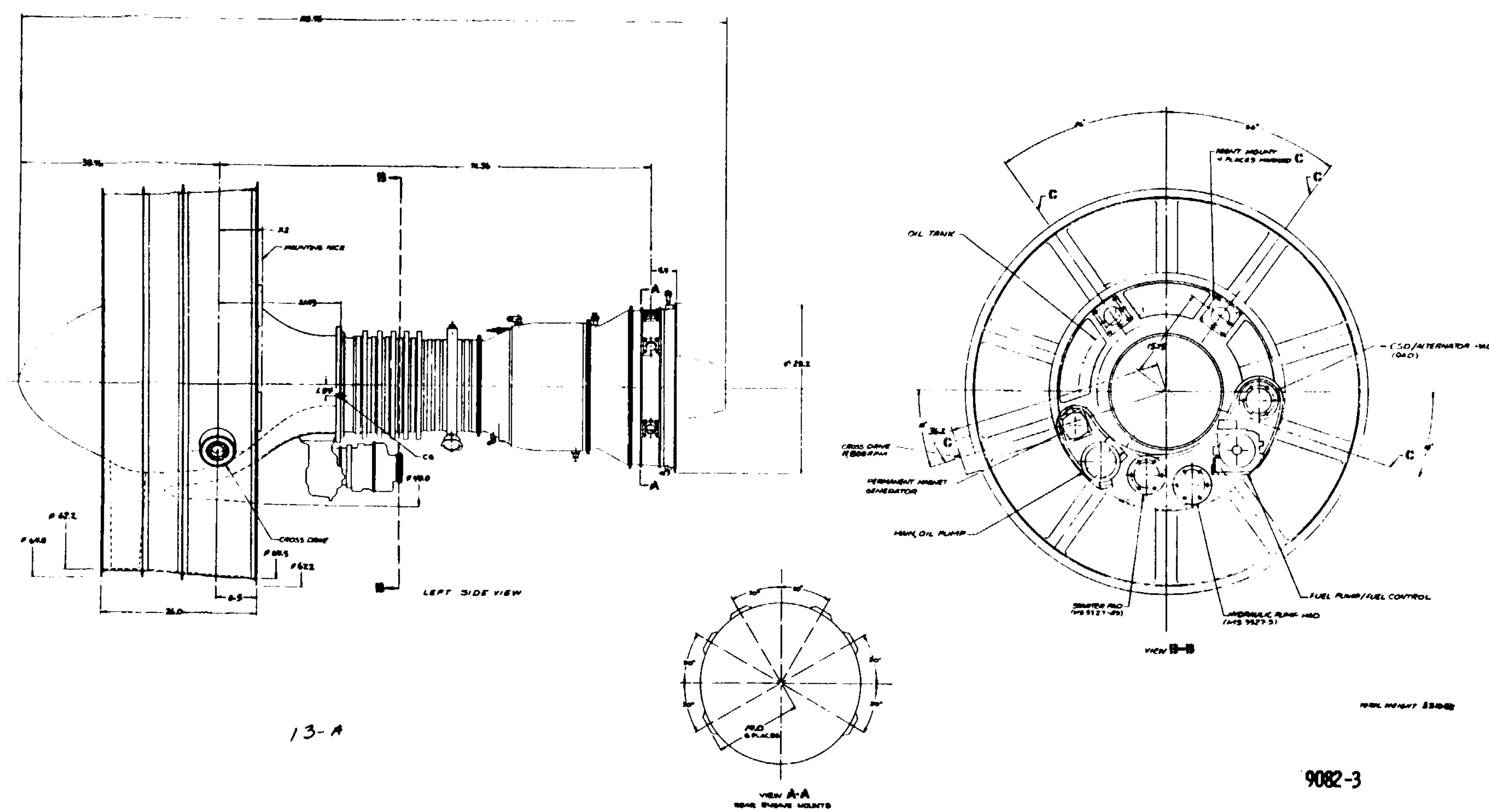
- Single engine mount at fan case OD
- Rear engine mount at turbine exhaust case
- Mount centered on cross drive
- MS3327-85 starter pad for airframer-supplied starter
- MS3327-5 accessory pad, HP driven—may be used as hydraulic pump drive
- HP-driven accessory pad for QAD-mounted CSD-driven alternator
- Cross drive output suitable for power transfer
- Doubly-redundant hydraulic Beta control system
- Triply-redundant electronic feedback from fan LVDT
- Electronic engine control to mate with fly-by-wire airframe control system
- Fan drive gearbox components that can be oriented for left or right side engine—cross drive output is on the horizontal center line

The power section for the engine is an Allison XT701 turboshaft. The fan is a 62-inch diameter Hamilton Standard variable pitch configuration. The fan disk, blade control system, etc, are the same as those described for the lift fan. The design point speed for the fan is 3543 rpm; because it is driven through a 3.33:1 reduction gear, this sets the power turbine speed at 11,810 rpm. The cross drive output speed is 13,420 rpm at the design point. Fan rotation is CCW viewed from rear; and the power turbine and HP turbine turn CW viewed from the rear. Cross drive rotation is CCW looking into the pad.

Thrust vectoring for VTO operation is accomplished by rotation of the complete engine/nacelle assembly about the cross shaft/mount center line.

TURBOSHAFT CENTER ENGINE

The center engine of each installation is the XT701-AD-700 turboshaft. An installation drawing with weight, center of gravity, and other pertinent dimensions is shown in Figures 5 and 6. The engine is unmodified except for control modifications. For a tilt nacelle configuration, the center engine oil system would also be modified for complete power section interchangeability.



13-A

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Figure 3. PD370-25A installation drawing.

B

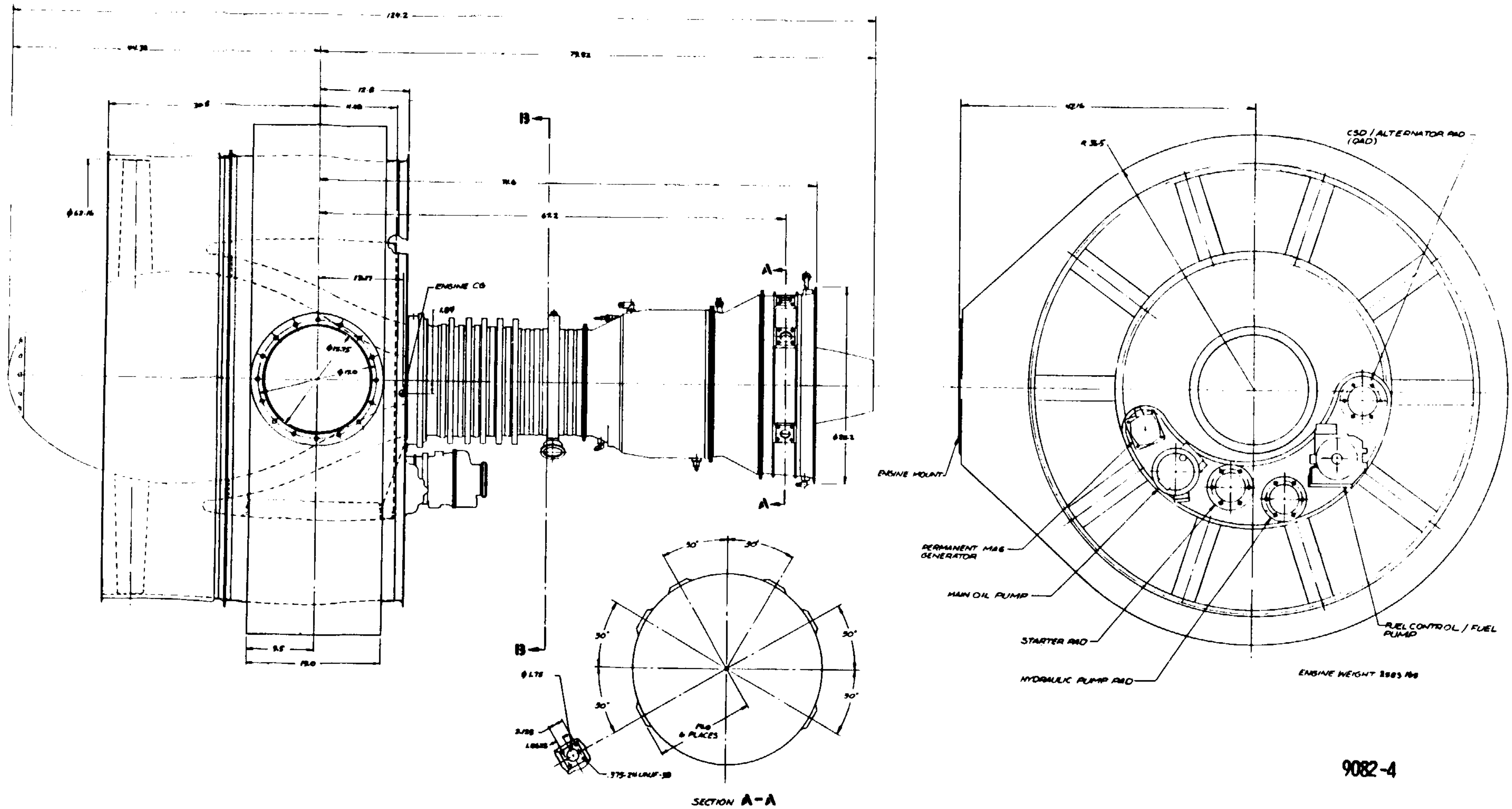
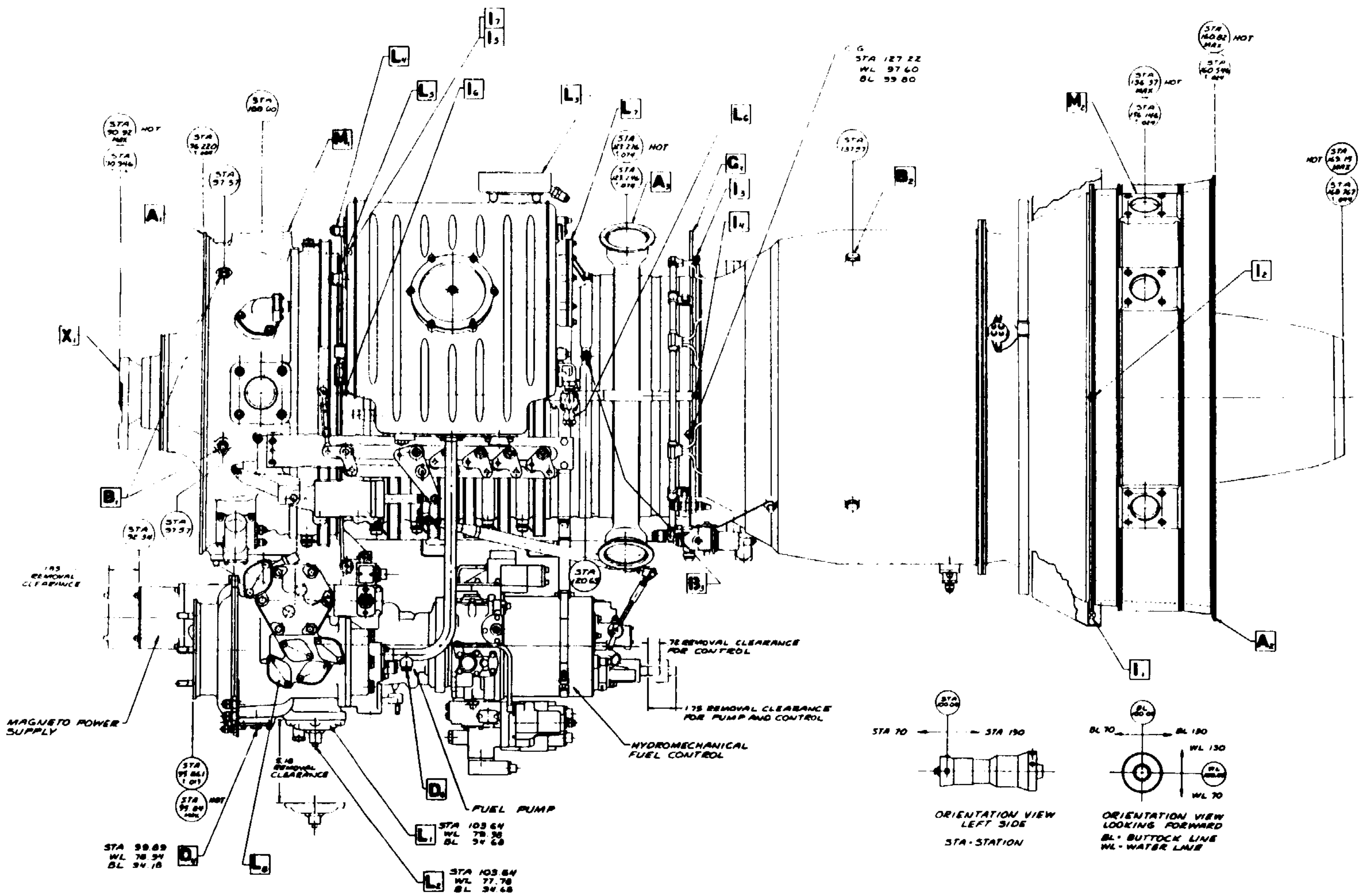


Figure 4. PD370-25E installation drawing.

15-A



SECTION	SYSTEM	CONNECTIONS
A	AIR	1 INLET DUCT FLANGE 2 EXHAUST DUCT FLANGE 3 10TH STAGE BLEED PORTS
B	INSPECTION PORTS	1 COMPRESSOR INLET HOUSING 2 OUTER COMBUSTION CASE 3 8TH STAGE COMPRESSOR
C	CONTROL	1 ENGINE SPEED ADJUSTMENT
D	DRAINS	1 ACCESSORY SEALS DRAIN 2 COMBUSTION DRAIN 3 FUEL FILTER DRAIN 4 ACCESSORY GEARBOX DRAIN 5 OIL TANK SCUPPER DRAIN 6 OIL TANK DRAIN 7 FUEL MANIFOLD DRAIN 8 OIL FILTER DRAIN
E	ELECTRICAL	1 ENGINE HARNESS DISCONNECT(J-1) 2 ENGINE HARNESS DISCONNECT(J-4)
F	FUEL	1 FUEL INLET 2 FUEL FILTER ΔP INDICATOR
G	GROUND HANDLING POINTS	1 ACCESSORY HOUSING 2 FRONT COMPR CASE 3 REAR COMPR CASE
L	LUBE	1 OIL FILTER 2 OIL FILTER ΔP INDICATOR 3 OIL TANK FILLER PORT 4 REMOTE FILL PORT 5 OVERFILL PORT 6 SPECTOGRAPHIC ANAL SAMPLE PORT 7 OIL TANK SIGHT GAGE 8 ENGINE SCAV PUMP SCREENS
M	MOUNTS	1 FRONT MOUNTS 2 REAR MOUNTS
P	ACCESSORY PADS	1 STARTER
X	MISCELLANEOUS	1 OUTPUT COUPLING 2 ENGINE INTERNAL WASH FITTING 3 HAND TURNING DRIVE CONNECTION
CM	CONDITION MONITORING	1 CONDITION MONITOR CONNECTOR(J-1) 2 CONDITION MONITOR CONNECTOR
I	INSTRUMENTATION	1 THRU 7 VIBRATION INSTRUMENTATION 8 THRU 16 COMPONENT LIMITING TEMP

TOTAL WEIGHT = 1135 POUNDS

Figure 5. XT701-AD-700 installation drawing, left side.

17- A

17- B

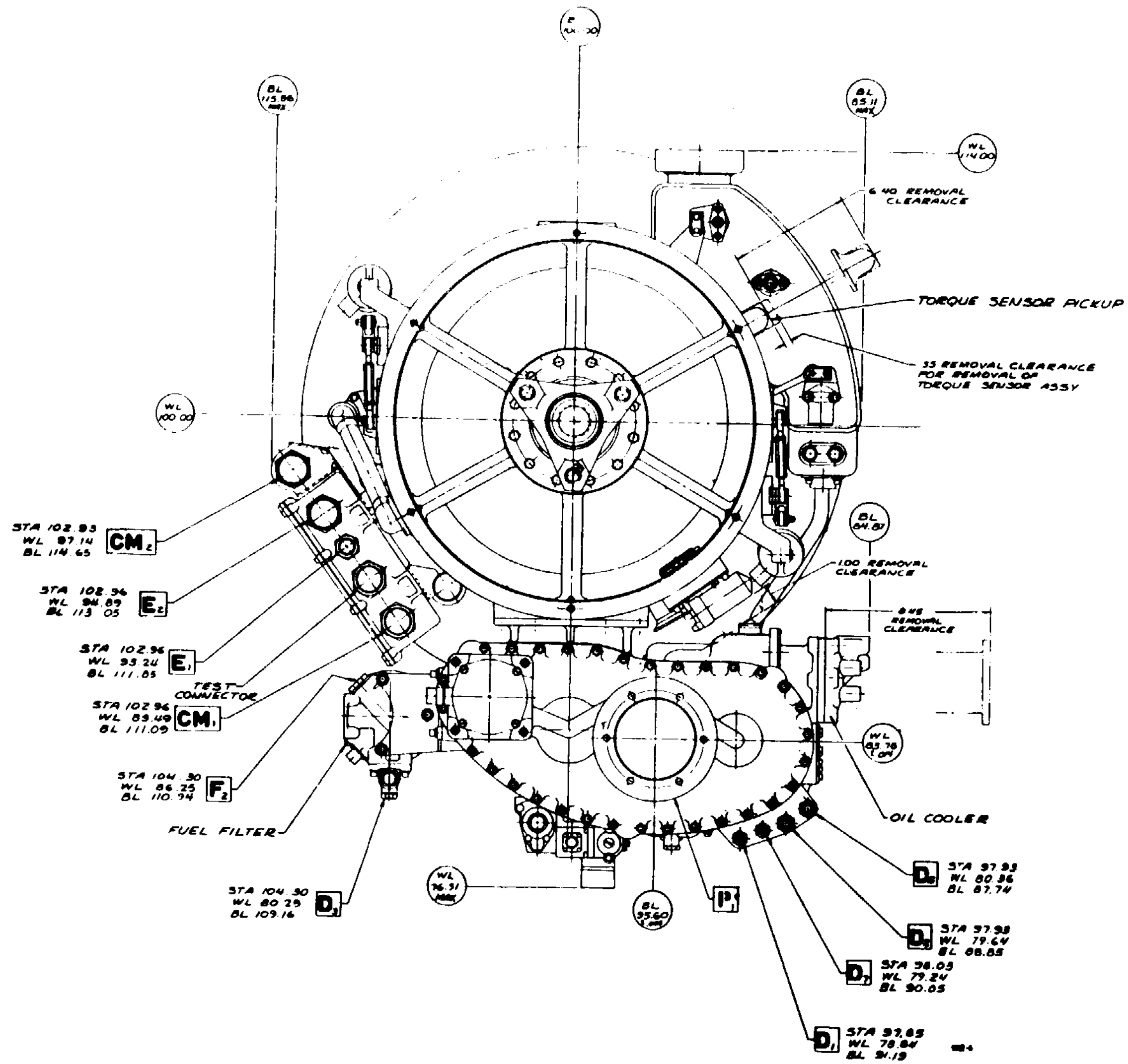


Figure 6. XT701 installation drawing, front.

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DESIGN REQUIREMENTS AND GOALS

The design requirements for the propulsion system are described in this section.

DESIGN POINT

The following guidelines governed the propulsion system design:

- VTOL mode of operation
- Sea level static, 90°F day conditions
- Intermediate Power (maximum thrust condition)
- Design for the more severe condition of three engines and three fans operating or two engines and three fans operating with one lift/cruise engine inoperative

However, the various system components are acted on by different loads in different modes of operation. There is not a single mode of operation that defines the maximum loads for all system components. Therefore, a thorough study of various operating modes was conducted to determine the design point of each component. The design limits are defined under the "Powers" subheading of the "Mechanical Limits" heading.

OPERATING ENVELOPE

The propulsion system will be designed for operation in a cruise mode up to 39,000 feet and a VTOL mode up to 2000 feet. The temperature range for operation is -65°F to +165°F.

DYNAMIC THRUST RESPONSE

The propulsion system will have a thrust response characteristic (time constant) of 0.2 seconds or less. Time constant as used here is defined as the time required to change thrust by 63.2% of the total thrust change after a step change in the power (or control) level.

STALL MARGIN

The fan stall margin requirements for the lift fan and the lift/cruise fans will not be less than:

- 20% for takeoff and landing
- 20% for cruise
- 10% for maximum control

$$\text{Stall margin} = \frac{P_{surge}}{P_{op\ pt}} \times \frac{W_{a\ op\ pt}}{W_{a\ surge}} - 1$$

where P_{surge} = total pressure at surge
$P_{op\ pt}$ = total pressure at operating point
$W_{a\ op\ pt}$ = airflow at operating point
$W_{a\ surge}$ = airflow at surge

SPECIFICATIONS

The propulsion system will be designed in accordance with Military Specifications MIL-E-5007D and MIL-P-26366.

Detroit Diesel Allison Prime Item Development Specification 844B covers the requirements of the XT701-AD-700 engine.

DESIGN LIFE

The lift fan assembly and the lift/cruise turbofan engine and all components thereof will be designed for 500 hours of operation with 500 research and technology aircraft duty cycles. The duty cycle is shown in Figure 7.

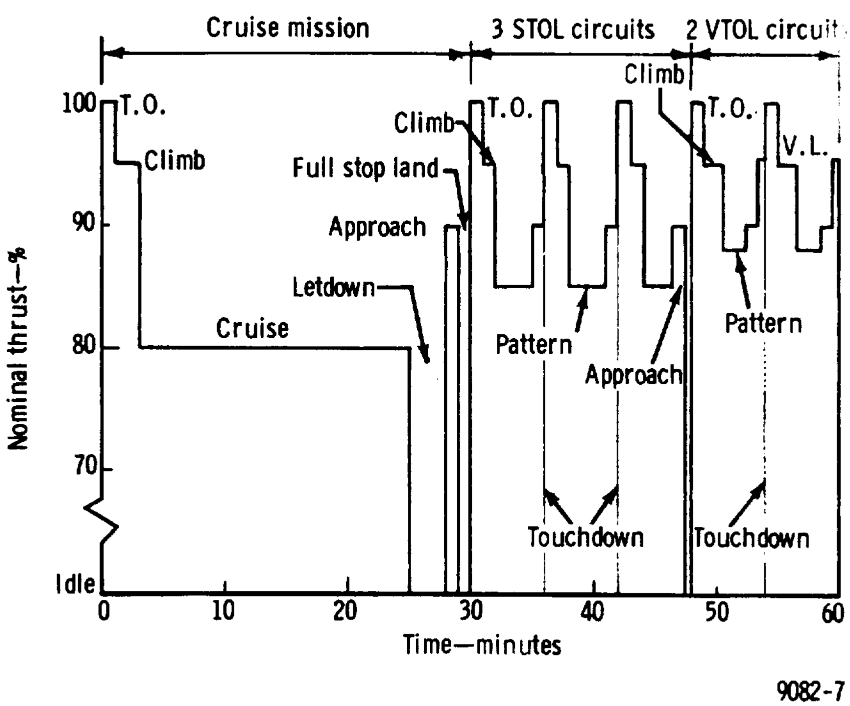

Figure 7. RTA duty cycle.

All propulsion system components will have a design life of 50 hours or more at a VTOL maximum thrust condition.

Maximum thrust is defined as the thrust available from three engines and three fans operating at intermediate power or from the intermediate power operation of two engines and three fans with one lift/cruise engine inoperative.

All propulsion system components will have a design life of 5 minutes or more during VTOL maximum attitude control operations.

MECHANICAL LIMITS

The propulsion system will be designed to operate with the acceleration loading envelopes shown in Figure 8.

The engine, gearing, clutch, shafting, front frame, bearings, and all components of both lift and lift/cruise fans will be capable of withstanding all loadings imposed by the loss of a blade shell, leading edge sheath, and fill.

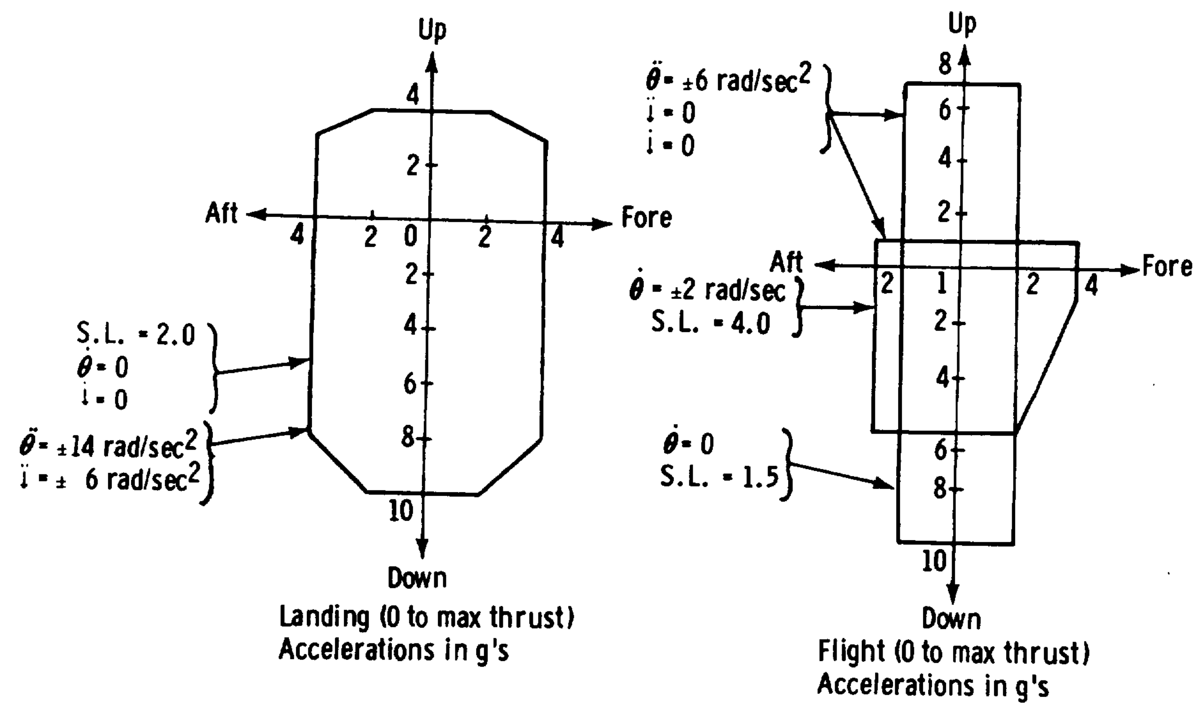

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Figure 8. Maneuver loading criteria.

Speeds

The design point speeds for individual components used in this design effort are shown in Figure 9. Maximum speeds for the engine gas generator turbine and power turbine are 15,450 and 12,300 rpm, respectively.

Powers

Fan powers for vertical takeoff balanced thrust were obtained from a performance analysis. This analysis considered core thrust, 100-hp accessory loads at the combiner box, losses in each gear mesh, and, in the case of one-engine-out operation, 3% water-alcohol augmentation to the operating engines.

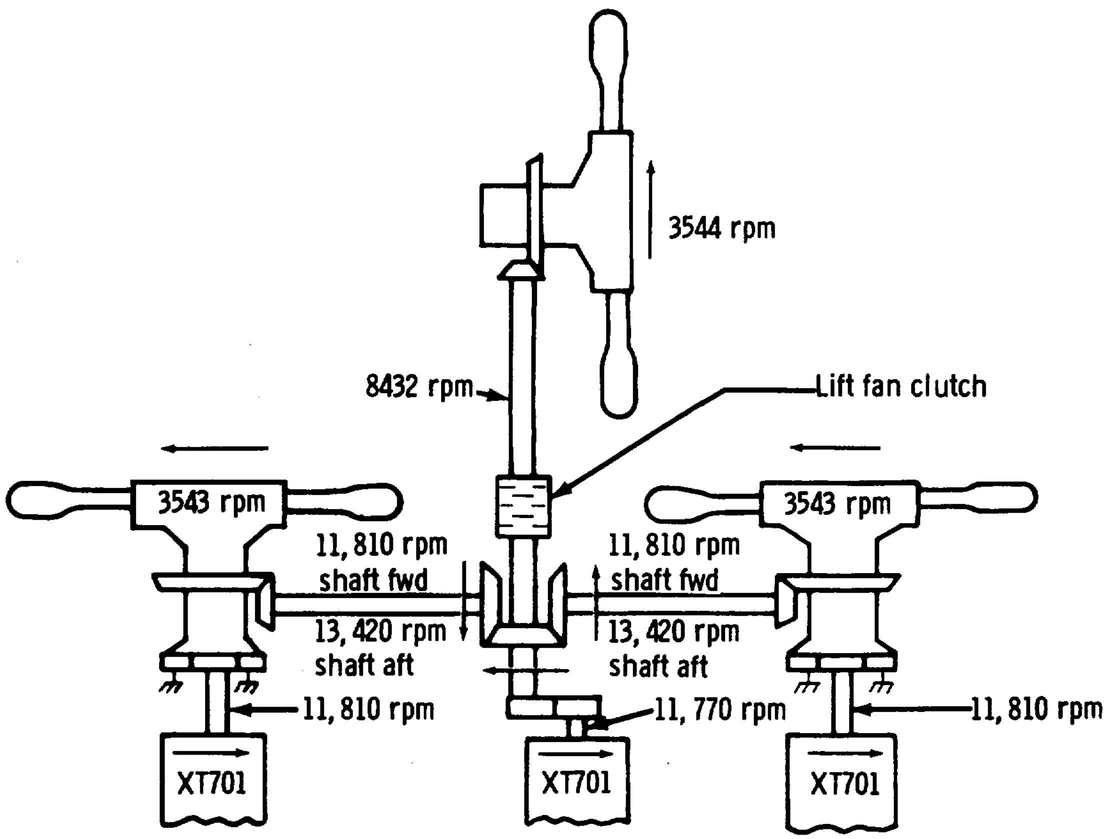


Figure 9. PD370-25 design point speeds.

The results of the performance analysis are summarized in the following tabulation:

	3 engines operating at normal TO power	3 engines operating at intermediate power	2 engines operating, right engine out, IP
Left L/C fan	6100 hp	8085 hp	5117 hp
Right L/C fan	6100 hp	8085 hp	5722 hp
Lift fan	6400 hp	8469 hp	5614 hp

Normal power is defined as the amount required to give the aircraft at vertical takeoff a 1.05 thrust-to-weight ratio with all engines operating.

Pitch and roll system powers were extrapolated from the analysis by the following rules:

- Maximum pitch and roll—35% power transfer for three engines operating
- Maximum pitch and roll—20% power transfer for one-engine-inoperative conditions
- Gear train losses 1/2% per mesh plus 20 hp for the lift fan, 30 hp for the L/C fan, and 40 hp for the combiner box windup losses.

The results are given in Table I. By referring to this table, the most severe conditions seen by each power system component can be determined.

Structure—Mounts

The criteria used to analyze the structural members of the engines except the tilt nacelle fan frame will include the maneuver loading criteria shown in Figure 8. The loading criteria imposed by Boeing airframe requirements and shown in Table II will be used in the tilt nacelle fan frame design. The loads specified in Table II represent ultimate loads which include a 1.5 safety factor; consequently, the structures were analyzed for design loads which are 2/3 of the values shown. Multiple loading criteria were used to sort out maximum vertical and gyroscopic conditions because thrust can either increase or decrease total loads; depending on the nacelle attachment. Positive values are for up-loading and negative values for down-loading. In addition, the following guidelines were established to analyze the individual member of the fan frame at the design load conditions:

1. Web—allow elastic buckling up to yield strength
2. Rings—stress up to yield with no buckling
3. Stiffeners—stress up to yield with no buckling
4. Struts—no buckling or yielding

The inlet housing stress to which the fan frame is attached was limited to the yield strength of the material.

TABLE I. SHAFT HORSEPOWER DISTRIBUTION

	Normal power—VTO			Intermediate power—VTO			Right engine out, intermediate power—VTO			Center engine out, intermediate power—VTO		
	Balanced thrust	Maximum pitch	Maximum roll	Balanced thrust	Maximum pitch	Maximum roll	Balanced thrust	Maximum pitch	Maximum roll	Balanced thrust	Maximum pitch	Maximum roll
Engine power, left	6741	6741	6741	8767	8767	8767	9065	9065	9065	9065	9065	9065
Engine power, right	6741	6741	6741	8767	8767	8767	----	----	----	9065	9065	9065
Engine power, center	5618	5618	5618	7502	7502	7502	7787	7787	7787	----	----	----
Fan power, left	6100	5000	4003	8085	6580	5208	5117	4551	3919	5743	5109	4595
Fan power, right	6100	5000	8197	8085	6580	10915	5722	5131	6866	5743	5109	6892
Fan power, center	6400	8600	6400	8469	11433	8469	5614	6737	5614	6238	7486	6238
Left X-shaft power	453	1564	2567	606	2103	3468	3853	4417	5045	3231	3861	4373
Right X-shaft power	453	1564	-1644	606	2103	-2233	-5751	-5187	-6931	3231	3861	2088
Center engine drive power	5618	5618	5618	7502	7502	7502	7787	7787	7787	0	0	0
Lift fan drive power	-6452	-8663	-6452	-8531	-11510	-8531	-5662	-6790	-5662	-6289	-7543	-6839

(-) Power out of combiner box.

The tilting engine fan core is a fabricated titanium structure. The material properties used to analyze the structure are as follows:

Material	6Al-4V titanium, solution-treated and aged
Yield strength	119.2 ksi (-3σ at 300°F)
Ultimate strength	132.8 ksi (-3σ at 300°F)

The material selected for the fixed nacelle engine structural mounting assembly is C355-T61 aluminum; properties to be used to analyze this structure are as follows:

Yield strength	27.5 ksi (-3σ at 300°F)
Ultimate strength	36.6 ksi (-3σ at 300°F)

Bearings

Bearing speed and load data with the exception of the fan thrust bearing loads can be determined with the data in Table I, Figure 9, and gear geometry.

Fan shaft axial thrust is a function of speed and beta angle (as noted in the following tabulation) and is expressed as a percentage of total fan thrust.

Beta angle (deg)	Relative fan thrust 100% speed	Relative fan thrust at 80% speed
-8	0.51	0.52
-4	0.49	0.50
0	0.47	0.48
+2	0.46	0.47

All bearings will be designed to meet the system requirements.

Gears

The cross shaft bevel gears will be designed to meet the following requirements:

Maximum power (out)	5045 hp
Maximum power (in)	6931 hp
Normal takeoff power (out)	606 hp

TABLE II. TILT NACELLE LOADING CRITERIA	
Engines in Conventional Flight Position	
Vertical (design to the most severe of the loading conditions):	+4.0g (acceleration of gravity) + 1.5 T_{max} (maximum nacelle thrust) +4.0g -3.5g + 1.5 T_{max} -3.5g
Lateral:	±2.5g
Longitudinal:	±3.0g 9g (crash)
Thrust:	1.5 T_{max} + 1.5g vertical
Engine seizure:	Equivalent to stopping rotating mass in 0.6 second 6022 N·m (53,300 in.-lb)
Gyroscopic:	±2.5 rad/sec yaw + 1.5 T_{max} + 1.5g vertical ±2.5 rad/sec pitch + 1.5 T_{max} + 4.5g vertical
Engines in Vertical Flight Position	
Vertical (design to the most severe of the loading conditions):	+5.0g + 1.5 T_{max} +5.0g -3.0g + 1.5 T_{max} -3.0g
Lateral:	±2.5g
Longitudinal:	±3.0g
Thrust:	1.5 T_{max} + 1.5g vertical
Engine seizure:	Equivalent to stopping rotating mass in 0.6 second 6022 N·m (53,300 in.-lb)
Gyroscopic:	±2.5 rad/sec yaw + 1.5 T_{max} + 1.5g vertical ±2.5 rad/sec pitch + 1.5 T_{max} + 1.5g vertical

The reduction gears in the L/C engines will be designed for the following:

Input design speed	11,810 rpm	
	PD370-25A	PD370-25E
Maximum power	9065 hp	10915 hp
Normal takeoff power	8767 hp	8085 hp

The differences in the preceding values for the -25A and -25E engines result from the location of the cross shaft relative to the reduction gear.

DESIGN GOALS

Design Approach

Designs for engine modifications and new components shall conform to a philosophy where weight is minimized (within state-of-the-art technology) while minimizing cost and maintaining adequate safety margins. The engine modifications will provide engine and drive capability which is consistent with operational requirements of the fans. Interchangeability of lift fan and lift/cruise fan components will be accomplished in the design.

Maintainability

In designing the propulsion system hardware, maintainability will be considered. Provisions will be included for easy access to hardware requiring service, inspection, and/or repair. "High risk" parts (those vulnerable to FOD, or those where life expectancy may be reduced by severe operating conditions) should have field joints to preclude the need for major teardown during a repair cycle. Also, access ports should be located in strategic areas of the assembly where borescope or other routine nondestructive tests can be performed. Self-contained lube/hydraulic/electrical systems will be used.

Fan Distortion

The fan will have no greater than a 5% thrust loss as a result of the following distortions, considered separately:

Pressure distortion

1. Inlet total pressure distortions* (six inches forward of fan face) of 15%

   or

2. Exit static pressure distortions* (six inches aft of fan stator exit) of 15%

*Distortion = $(P_{max} - P_{min})/P_{avg}$ where P_{max}, P_{min}, and P_{avg} = maximum, minimum, and average total pressure, respectively.

Temperature distortion

1. Temperature over 50% of inlet face at least 50°F above ambient inlet temperature

   or

2. Changes of average temperature of 50°F/sec for 1/2 second

The area which would cause a performance loss no greater than 5% will be determined.

PROPULSION SYSTEM PERFORMANCE

PROPULSION SYSTEM CHARACTERISTICS AND CAPABILITIES

The propulsion system is powered by three XT701-AD-700 turboshaft engines. The engines have an intermediate power rating established during the Heavy Lift Helicopter program. Integration of the variable-pitch fan and engine provides additional power from the turbofan because of the supercharging effects. The total three-engine three-fan intermediate power thrust can not be used to size the aircraft because of the requirement for a thrust-to-weight ratio of 1.03 during a one-engine-inoperative vertical takeoff or landing. Thus, the sizing condition is for one of the turbofan engines inoperative.

The total thrust available with engines at intermediate power on a 90°F day from three engines operating and two engines operating (one lift/cruise turbofan out) are summarized as follows:

	Thrust (lb)	
	3E-3F	2E-3F
Uninstalled	37,114	27,102
Installed with McDonnell factors	33,324	24,279
Installed with Boeing factors	35,518	25,780

Additional takeoff thrust could be achieved by adding a water-alcohol injection system to the engines. A 3% increase in engine flow and reduced temperature with water-alcohol injection at compressor inlet produces the following thrust augmentation:

- Intermediate power, 90°F day, 2E-3F, one lift/cruise engine inoperative

	Thrust (lb)	
	Dry	With W/A
Uninstalled	27,102	29,889
Installed with McDonnell factors	24,279	26,900
Installed with Boeing factors	25,780	28,451

Roll and pitch attitude control is accomplished by power transfer and fan pitch angle adjustment. Typical control margins for the propulsion system are as follows:

- Uninstalled, intermediate power, vertical flight, SLS, 90°F day

Roll control

	3E-3F	2E-3F, dry	2E-3F, wet
Level flight fan pitch angle, degrees	+1.1	-7.6	-5.6
Level flight fan thrust, lb	12,373	9,034	9,963
Controlled fan pitch angle, degrees	+6.9	+.6	+5.0
Controlled fan thrust, lb	14,348	12,187	13,831
Control margin, %	16	35	39

Pitch control

	3E-3F
Level flight fan pitch angle, degrees	+2.1
Level flight fan thrust, lb	12,368
Controlled fan pitch angle, degrees	+7.3
Controlled fan thrust, lb	14,205
Control margin, %	15

The following are the fan stall margins for the propulsion system:

	Stall margin %
Vertical flight, uninstalled, SLS, intermediate power, 3E-3F	20
Vertical flight, uninstalled, SLS, intermediate power, 3E-3F, max pitch control	10
Cruise, uninstalled, intermediate power, 0.4 M_N, 10,000-ft altitude	20

FAN AERODYNAMIC DESIGN

Aerodynamic studies were conducted by Hamilton Standard to define the characteristics and performance of a high-bypass-ratio fan for the NASA/Navy RTA. The fan rotor was to meet the needs of both the lift and lift/cruise fans. The performance and size of a lift/cruise fan studied under NASA contract NAS3-20033 provided a basis for the 62-inch diameter high-bypass-ratio turbofan design as reported herein.

Design Requirements

The requirement of lift fan and lift/cruise fan rotor commonality and the results of a detailed blade structural analysis led to changes in rotor aerodynamic design which included the following:

- The number of blades went from 26 to 22.
- Blade root thickness ratio went from 0.11 to 0.125.
- Blade root chord went from 6.1 to 6.5 in.
- Hub/tip ratio went from 0.425 to 0.454.

In addition, the fan bypass ratio was changed from the 9.5 associated with the earlier fan studies to a value of 13.5, consistent with the RTA's XT701 propulsion system.

The RTA fan design was intended to cover the performance requirements for the two different aircraft designs by BMAD and MCAIR. The individual requirements for the two companies were very similar (Table III), allowing a common design for both aircraft. These conditions may be described as the prevailing "design points" of the variable-pitch fan for the RTA.

TABLE III. FAN OPERATING REQUIREMENTS

	Lift/Cruise		Lift	
	BMAD	MCAIR	BMAD	MCAIR
Normal takeoff				
Thrust, lb	9,600	9,400	9,660	9,396
P_R	1.175	1.181	1.179	1.181
Specific airflow, $lb/ft^2/sec$	35.9	36.2	36.2	36.2
Maximum control				
Thrust, lb	11,600	11,400	N/A	N/A
P_R	1.213	1.221	N/A	N/A
Specific airflow, $lb/ft^2/sec$	39.3	39.8	N/A	N/A
Engine out V-land				
Thrust, lb	8,600	8,600	8,600	8,600
P_R	1.149	1.158	1.160	1.160
Specific airflow, $lb/ft^2/sec$	33.6	34.2	36.3	36.3

To investigate the suitability of the rotors to meet the requirements of the lift and the lift/cruise fans, the rotor blade meridional velocity profiles on the lift and lift/cruise fans were calculated. The velocity profiles were found to be highly warped as shown in Figure 10. This "mismatch" would lead to high incidence losses for the lift fan. The lift and lift/cruise inlet flow paths were redesigned to provide similar velocity profiles at the rotor inlets. The similarity in the spanwise distributions of the meridional velocities obtained from flow path redesign, which made commonality possible, is shown in Figure 11. The refined lift/cruise fan and the lift fan inlet flowpaths are shown in Figure 12. Both fans have a rotor inlet hub-to-tip-diameter ratio of 0.454, increasing to 0.512 at the rotor trailing edge. The splitter and both stator blade rows for the lift/cruise fan and the stators for the lift fan are also shown in this illustration.

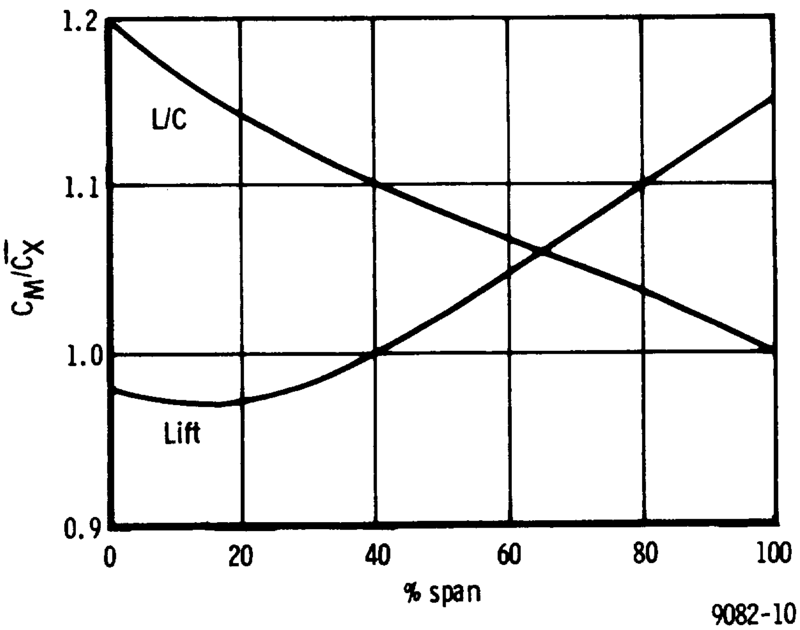
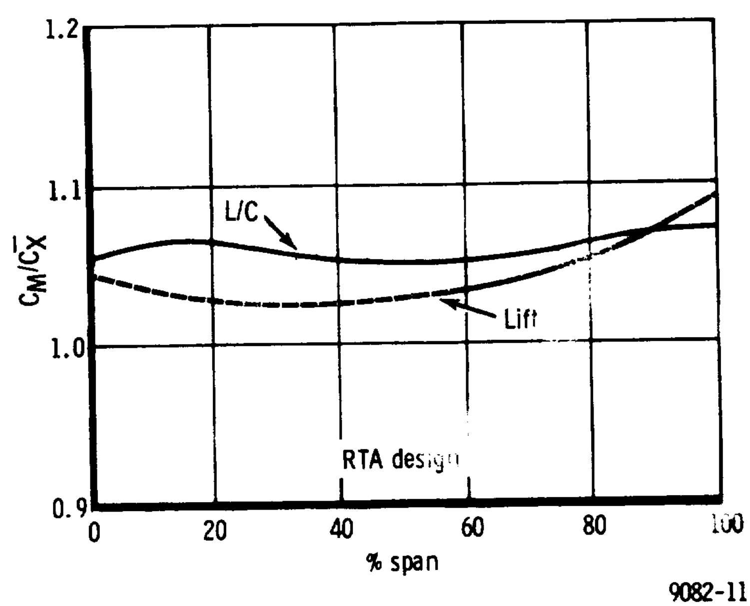


Figure 10. Meridional velocity distribution comparison—original design (rotor leading edge).

Figure 11. Meridional velocity distribution comparison—refined design (rotor leading edge).



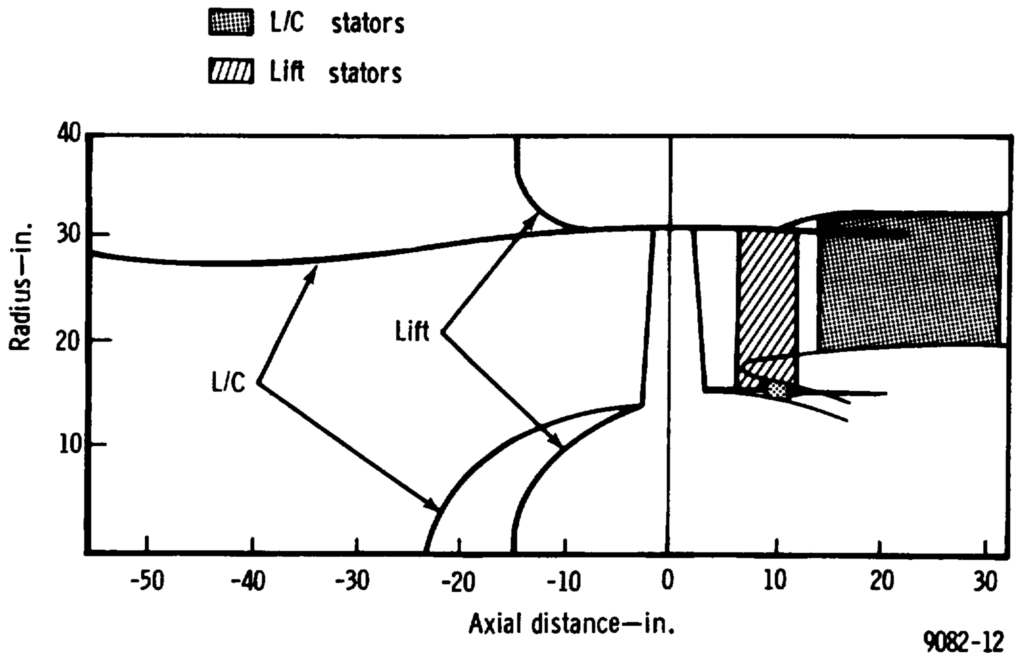


Figure 12. Lift and lift/cruise fan flow paths.

Fan Characteristics

The aerodynamic geometry of the fan was determined, using a compressible streamline curvature program. The aerodynamic details of the lift/cruise fan rotor, bypass stator, engine stator and lift fan rotor and stator are presented in Tables IV through VIII. The data are presented for the normal take-off condition at blade angles of $\Delta\beta = -4.1°$ for the lift/cruise and $\Delta\beta = -4.7°$ for the lift fan.

The characteristics are shown at a root, mean, and tip streamline for both fans and also for the split streamline for the lift/cruise fan. The streamline numbers and the associated diameters listed in these tables are different for the two fans as more streamlines were analyzed for the lift/cruise fan to include the core engine inlet.

The geometric characteristics for the fans are shown in Tables IX through XIII. Although the rotors are common for the two fans, slight differences in the inlet condition and in the performance have resulted in small changes in the pitch setting (β_1* and β_2*), incidence (i), and deviation (δ) angles. Therefore, the geometric characteristics are presented for both rotors.

Performance

The detail geometries of the refined 22-bladed fan design were used to calculate fan performance for comparison with the performance maps prepared for the 26-bladed lift/cruise fan under the earlier NASA contract (NAS3-20033). The performance comparison at three blade pitch angles and 85% efficiency is presented in Figure 13.

TABLE IV. LIFT/CRUISE FAN AERODYNAMIC DATA—ROTOR										
(P_R = 1.18, $W\sqrt{\theta}/\delta A$ = 36, 100% $N/\sqrt{\theta}$, $\Delta\beta$ = -4.1°)										
Inlet										
SL	d (in.)	M_M	M	α (deg)	β (deg)	ϕ (deg)	P (lb/ft^2)	T (°R)	Z	D
2	29.5	0.508	0.650	0	38.5	15.7	2099	550	---	---
5	32.2	0.517	0.681	0	40.5	14.0	2099	550	---	---
13	46.4	0.508	0.815	0	51.4	6.3	2099	550	---	---
24	60.5	0.516	0.978	0	57.2	0	2099	550	---	---
Exit										
2	32.9	0.490	0.501	34.8	11.7	11.5	2512	583	0.109	0.409
5	35.2	0.469	0.495	33.7	18.8	8.8	2522	582	0.069	0.437
13	47.6	0.465	0.638	23.4	43.1	5.9	2479	578	0.032	0.333
24	60.5	0.494	0.804	19.6	52.1	1.4	2491	581	0.064	0.266
Refer to Appendix B for explanation of symbols.										

TABLE V. LIFT/CRUISE FAN AERODYNAMIC DATA—BYPASS STATOR									
(P_R = 1.18, $W\sqrt{\theta}/\delta A$ = 36, 100% $N/\sqrt{\theta}$, $\Delta\beta$ = -4.1°)									
Inlet									
SL	d (in.)	M_M	M_A	α (deg)	ϕ (deg)	P (lb/ft^2)	T (°R)	Z	D
5	39.1	0.572	0.638	26.4	2.9	2522	582	---	---
13	50.2	0.462	0.500	22.5	3.5	2479	578	---	---
24	63.3	0.418	0.450	21.8	6.7	2491	581	---	---
Exit									
5	40.4	0.444	---	0	-0.7	2472	582	0.092	0.451
13	51.7	0.449	---	0	-0.3	2475	578	0.011	0.278
24	64.1	0.450	---	0	-0.6	2479	581	0.039	0.223
Refer to Appendix B for explanation of symbols.									

TABLE VI. LIFT/CRUISE FAN AERODYNAMIC DATA—ENGINE STATOR

(P_R = 1.18, $W\sqrt{\theta}/\delta A$ = 36, 100% $N/\sqrt{\theta}$, $\Delta\beta$ = -4.1°)

SL	d (in.)	M_M	M_A	α (deg)	ϕ (deg)	P (lb/ft^2)	T (°R)	Z	D
Inlet									
1	31.9	0.411	0.542	40.7	-5.3	2506	583	---	---
3	33.6	0.419	0.533	38.3	-5.4	2515	583	---	---
5	35.2	0.426	0.528	36.2	-5.9	2522	582	---	---
Exit									
1	31.6	0.395	---	0	-7.9	2447	583	0.141	0.434
3	33.3	0.415	---	0	-8.6	2506	583	0.022	0.395
5	34.9	0.371	---	0	-8.0	2476	582	0.113	0.464

Refer to Appendix B for explanation of symbols.

TABLE VII. LIFT FAN AERODYNAMIC DATA—ROTOR

(P_R = 1.18, $W\sqrt{\theta}/\delta A$ = 36, 100% $N/\sqrt{\theta}$, $\Delta\beta$ = -4.7°)

SL	d (in.)	M_M	M	α (deg)	β (deg)	ϕ (deg)	P (lb/ft^2)	T (°R)	Z	D
Inlet										
2	31.0	0.526	0.677	0	39.0	15.6	2099	550	---	---
10	46.8	0.496	0.811	0	52.3	4.2	2099	550	---	---
20	60.6	0.502	0.971	0	58.8	-0.8	2099	550	---	---
Exit										
2	34.0	0.526	0.544	31.1	15.0	8.4	2501	582	0.084	0.361
10	47.5	0.456	0.631	23.6	43.7	3.2	2472	578	0.033	0.328
20	60.6	0.463	0.776	21.7	53.4	0.0	2515	583	0.063	0.293

Refer to Appendix B for explanation of symbols.

TABLE VIII. LIFT FAN AERODYNAMIC DATA—STATOR									
(P_R = 1.18, $W\sqrt{\theta}/\delta A$ = 36, 100% $N/\sqrt{\theta}$, $\Delta\beta$ = -4.7°)									
Inlet									
SL	d (in.)	M_M	M_A	α (deg)	ϕ (deg)	P (lb/ft^2)	T (°R)	Z	D
2	34.4	0.510	0.598	31.5	1.5	2501	582	---	---
10	47.8	0.467	0.508	23.0	1.9	2472	578	---	---
20	60.5	0.473	0.508	21.3	-0.4	2516	583	---	---
Exit									
2	34.6	0.460	---	0	0.6	2455	582	0.093	0.395
10	47.9	0.461	---	0	0.4	2467	578	0.013	0.261
20	60.5	0.479	---	0	-0.4	2499	583	0.043	0.261
Refer to Appendix B for explanation of symbols.									

TABLE IX. LIFT/CRUISE FAN BLADE GEOMETRY—ROTOR								
Airfoil series - DCA Tip aspect ratio - 2.20				Number of blades - 22 Inlet area - 2400 in.^{2} Exit area - 2229 in.^{2}				
SL	d_1 (in.)	d_2 (in.)	τ/b	t/b	$\beta 1^*$ (deg)	$\beta 2^*$ (deg)	i (deg)	δ (deg)
2	29.5	32.9	0.688	0.122	33.3	6.5	5.1	5.2
5	32.2	35.2	0.742	0.110	37.9	14.3	2.6	4.5
13	46.4	47.6	0.983	0.061	49.8	40.3	1.6	2.8
24	60.5	60.5	1.189	0.026	60.4	50.1	-2.2	1.9
Refer to Appendix B for explanation of symbols.								

TABLE X. LIFT/CRUISE FAN BLADE GEOMETRY—BYPASS STATOR

Airfoil series - 65/CA	Number of vanes - 10
Aspect ratio - 0.76	Inlet area - 2105 $in.^2$
	Exit area - 2113 $in.^2$

SL	d_1 (in.)	d_2 (in.)	τ/b	t/b	$\alpha 1^*$ (deg)	$\alpha 2^*$ (deg)	i (deg)	δ (deg)
5	39.1	40.4	0.733	0.09	28.2	-14.4	-1.8	14.4
13	50.2	51.7	0.942	0.09	28.6	-11.8	-6.1	11.8
24	63.3	64.1	1.182	0.09	30.4	-14.1	-8.5	14.1

Refer to Appendix B for explanation of symbols.

TABLE XI. LIFT/CRUISE FAN BLADE GEOMETRY—ENGINE STATOR

Airfoil series - 65/CA	Number of vanes - 87
Aspect ratio - 0.78	Inlet area - 174 $in.^2$
	Exit area - 172 $in.^2$

SL	d_1 (in.)	d_2 (in.)	τ/b	t/b	$\alpha 1^*$ (deg)	$\alpha 2^*$ (deg)	i (deg)	δ (deg)
1	31.9	31.6	0.539	0.09	41.8	-14.5	-1.1	14.5
3	33.6	33.3	0.568	0.09	38.7	-13.3	-0.4	13.3
5	35.2	34.9	0.597	0.09	34.6	-12.1	1.6	12.1

Refer to Appendix B for explanation of symbols.

TABLE XII. LIFT FAN BLADE GEOMETRY—ROTOR

Airfoil series - DCA	Number of blades - 22
Tip aspect ratio - 2.20	Inlet area - 2400 $in.^2$
	Exit area - 2229 $in.^2$

SL	d_1 (in.)	d_2 (in.)	τ/b	t/b	$\beta 1^*$ (deg)	$\beta 2^*$ (deg)	i (deg)	δ (deg)
2	31.0	34.0	0.718	0.116	36.8	11.0	2.4	4.1
10	46.8	47.5	0.987	0.061	50.8	40.9	1.5	2.9
20	60.6	60.6	1.188	0.026	61.0	50.7	-2.2	2.7

Refer to Appendix B for explanation of symbols.

TABLE XIII. LIFT FAN BLADE GEOMETRY—STATOR								
	Airfoil series - 65/CA				Number of vanes - 28			
	Aspect ratio - 2.50				Inlet area - 2215 $in.^2$			
					Exit area - 2215 $in.^2$			
SL	d_1 (in.)	d_2 (in.)	σ/b	t/b	$\alpha 1^*$ (deg)	$\alpha 2^*$ (deg)	i (deg)	δ (deg)
2	34.4	34.6	0.634	0.09	33.1	-14.2	0.1	14.2
10	47.8	47.9	0.870	0.09	29.0	-11.4	-6.0	11.4
20	60.5	60.5	1.093	0.09	29.8	-12.7	-8.5	12.7
Refer to Appendix B for explanation of symbols.								

Figure 14 gives a similar comparison of supercharging performance at 100% $N\sqrt{\theta}$ for the lift/cruise fan root. The performance shown in the previous curve establishes that the current fan design is very similar in performance to the previous design, especially in the projected operating range. A small improvement exists in the operating efficiencies of the new design for both bypass and root (supercharge) performance.

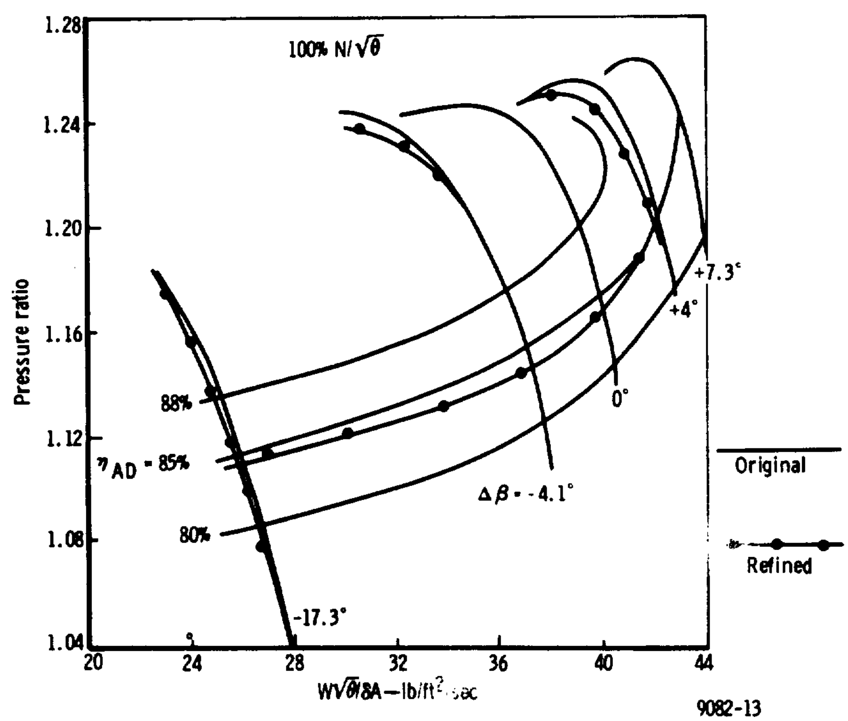


Figure 13. Original and refined performance comparison.

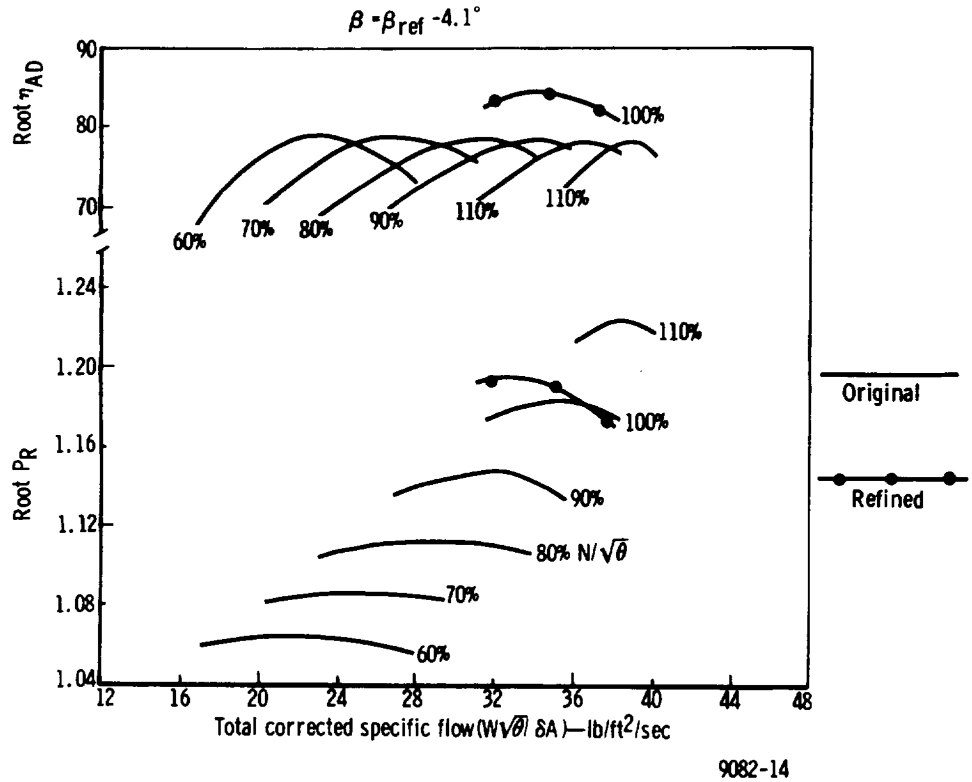


Figure 14. Original and refined fan supercharge performance comparison.

The performance of the lift fan was calculated with its particular incidence angles and flow path and compared with the lift/cruise fan rotor performance as shown in Figure 15. The closeness of the current fan performance to the previous design and the lift to the lift/cruise fan resulted in a decision to retain the original fan performance maps as representative of the performance of the 22-blade fan design for both the lift and lift/cruise fans.

The fan maps which represent the V/STOL RTA lift and lift/cruise fan performance are presented for a series of five blade pitch settings in Figures 16 through 27.

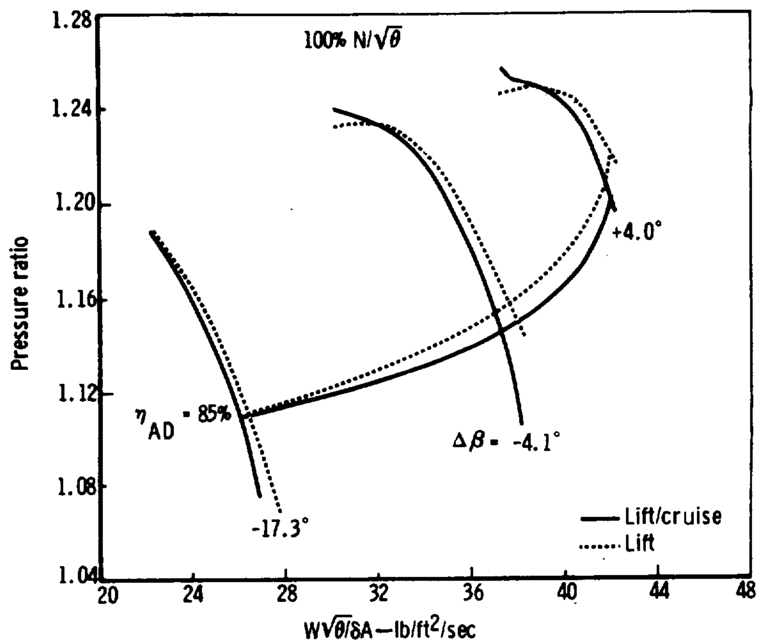
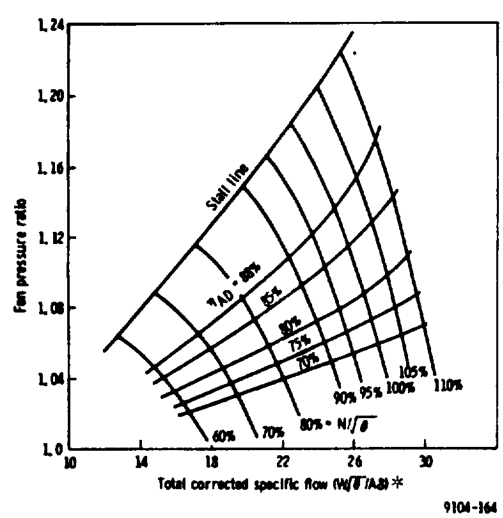


Figure 15. Lift/cruise and lift fan performance comparison.



*lb/ft^2/sec

Figure 16. Fan performance map, $\beta = \beta_{ref} - 17.2°$.

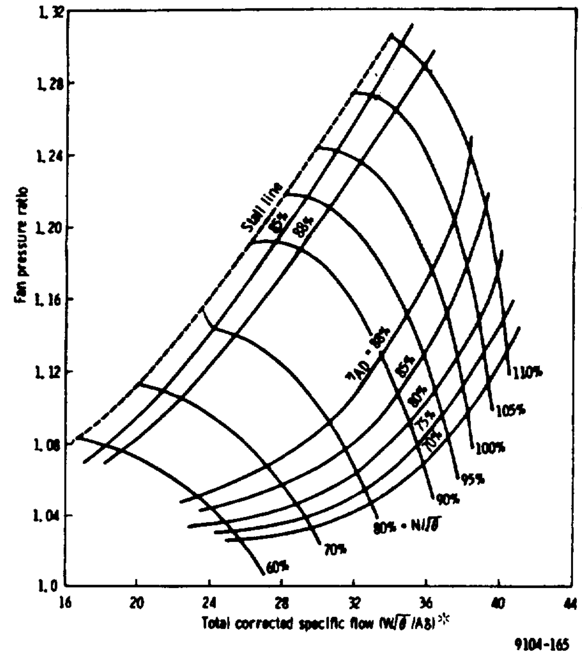


Figure 17. Fan performance map, $\beta = \beta_{ref} - 4.1°$.

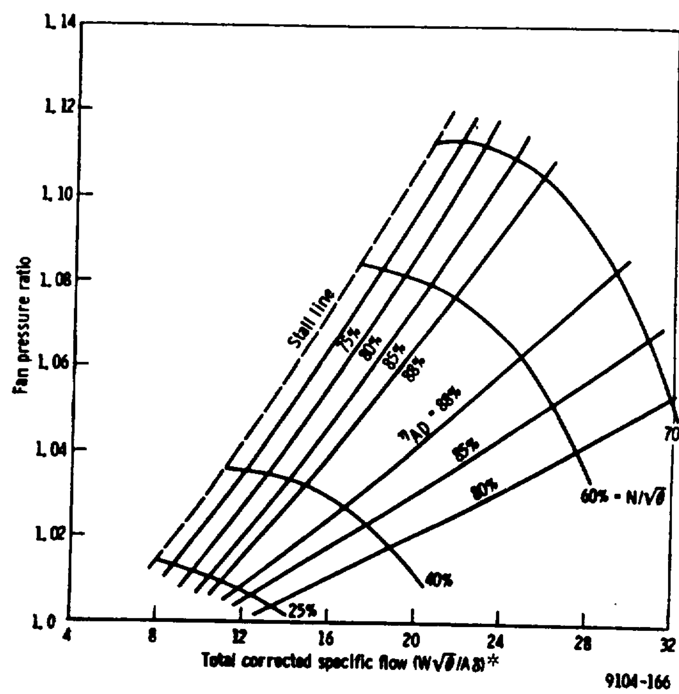


Figure 18. Fan performance map, $\beta = \beta_{ref}$, 25-75% corrected speed.

*lb/ft^2/sec

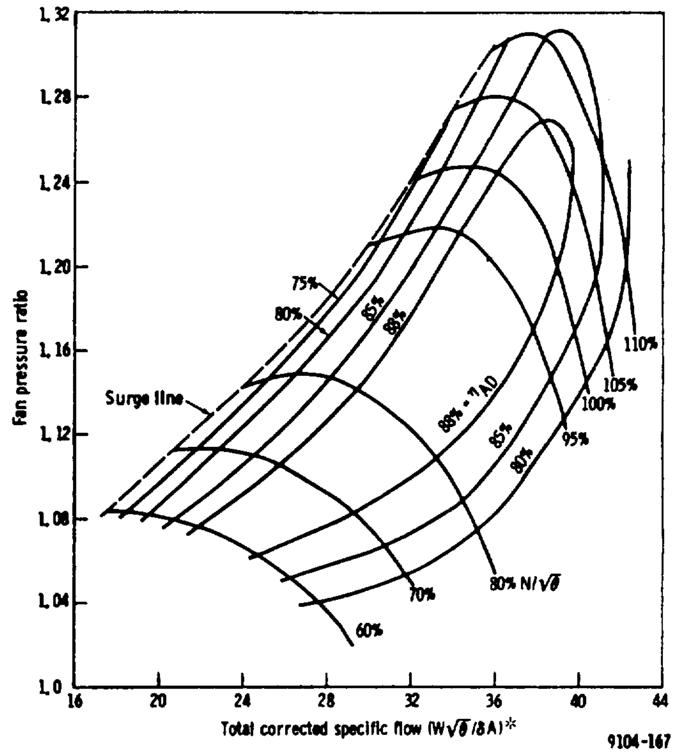


Figure 19. Fan performance map, β = β_{ref}, 60-110% corrected speed.

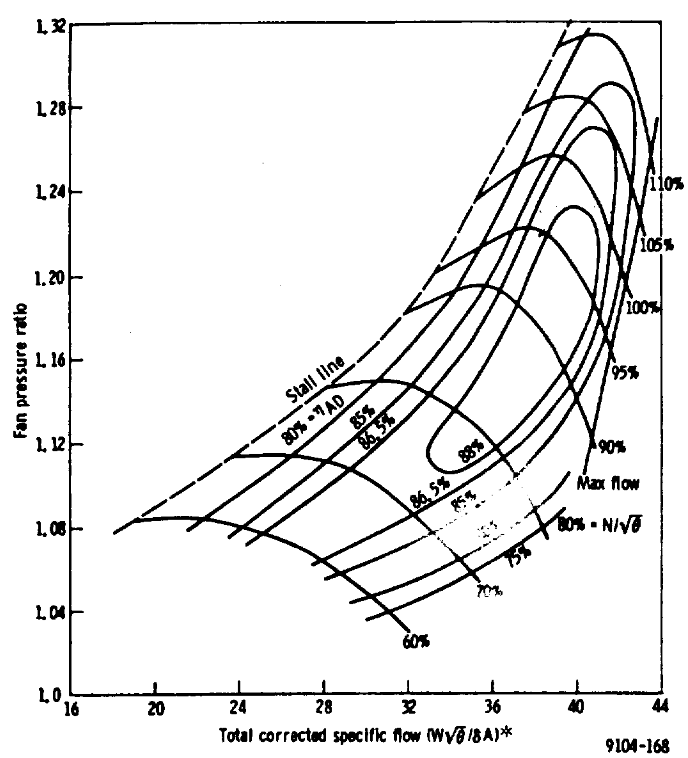


Figure 20. Fan performance map, β = β_{ref} + 4.1°.

*lb/ft^2/sec

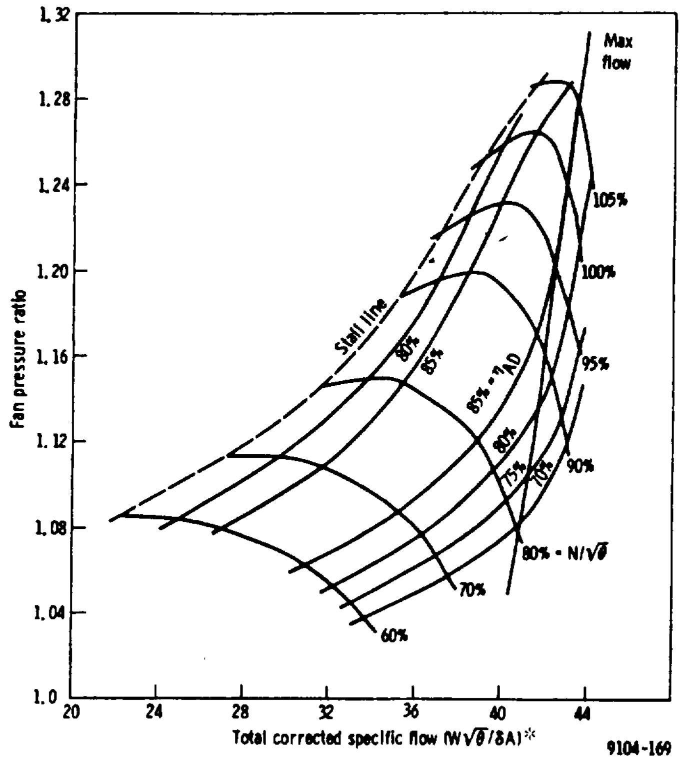


Figure 21. Fan performance map, $\beta = \beta_{ref} + 7.3°$.

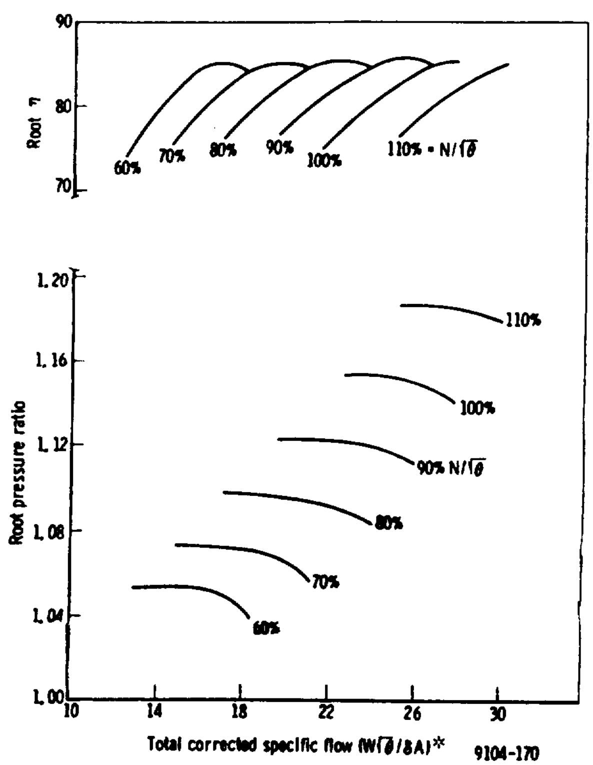


Figure 22. Fan supercharging performance, $\beta = \beta_{ref} - 17.2°$.

*lb/ft^2/sec

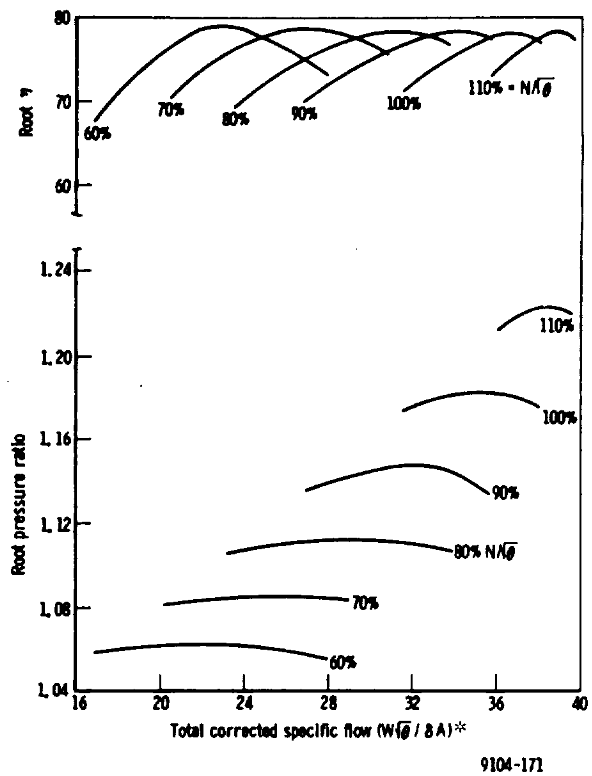


Figure 23. Fan supercharging performance, $\beta = \beta_{ref} - 4.1°$.

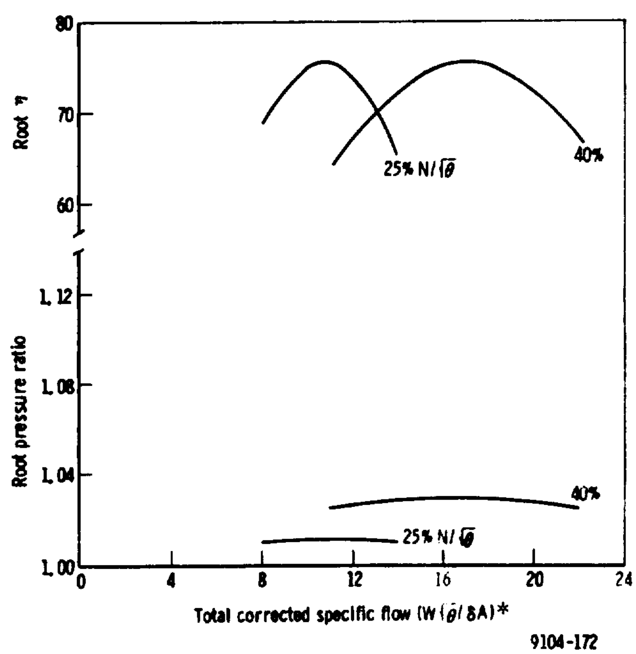


Figure 24. Fan supercharging performance, $\beta = \beta_{ref}$, 25-40% corrected speed.

*lb/ft^2/sec

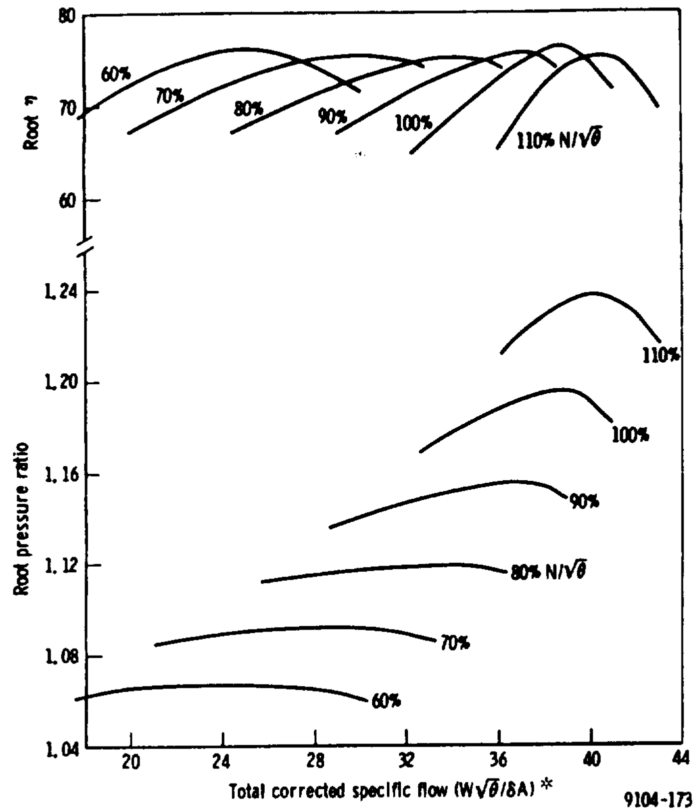


Figure 25. Fan supercharging performance, $\beta = \beta_{ref}$, 60-110% corrected speed.

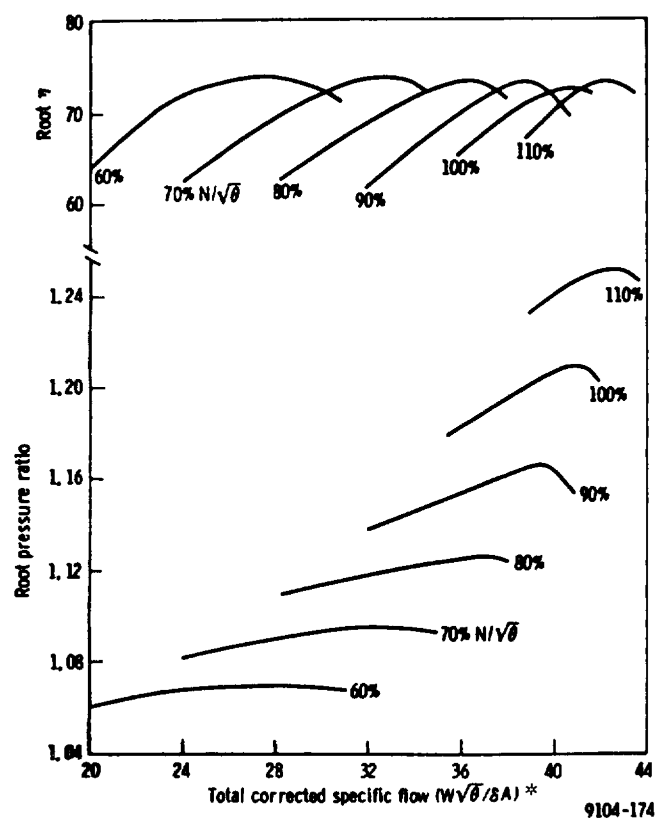


Figure 26. Fan supercharging performance, $\beta = \beta_{ref} + 4.1°$.

*$lb/ft^2/sec$

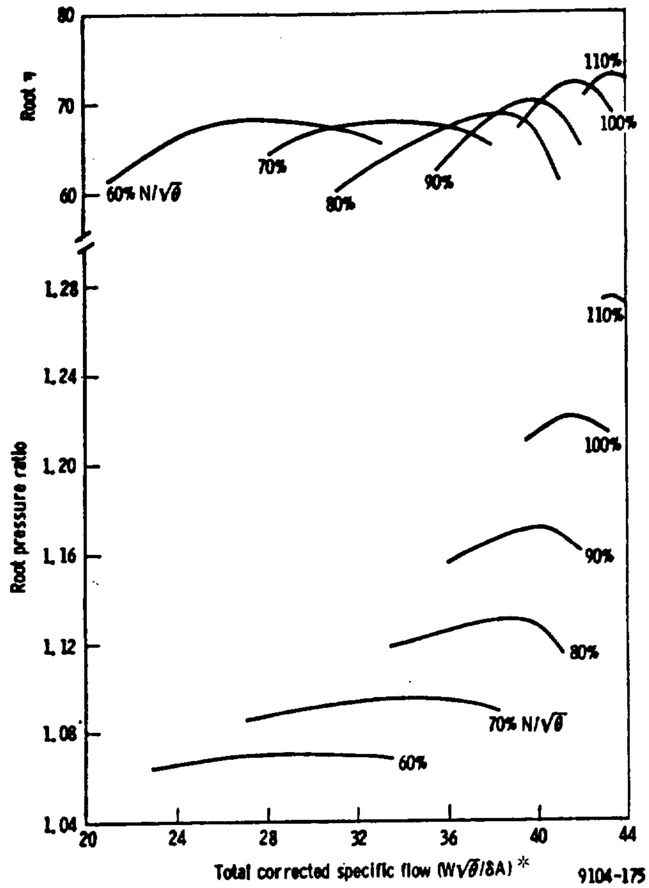


Figure 27. Fan supercharging performance, $\beta = \beta_{ref} + 7.3°$.

*lb/ft²/sec

Inlet Distortion

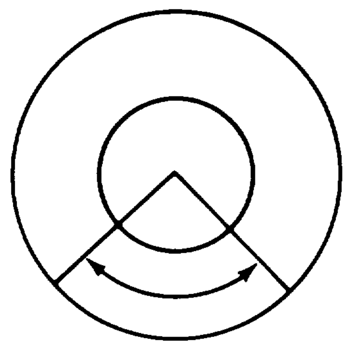
The effects of fan inlet and exit pressure and temperature distortion were analyzed in accordance with the statement of work and supplement the results of the parallel compressor analysis which was conducted under NASA contract NAS3-20033. The statement of work required the calculation of the area which would cause a performance loss no greater than 5% as a result of the following distortions, considered separately:

- Pressure
  1. Inlet total pressure distortions* (6 inches forward of fan face) of 15%
  2. Exit static pressure distortions* (6 inches aft of fan stator exit) of 15%
- Temperature
  1. Temperature over 50% of inlet face at least 50°F above ambient inlet temperature
  2. Changes of average temperature of 50°F/sec for 1/2 second

*Distortion = $(P_{max} - P_{min})/P_{avg}$

The effects of these specified distortions were calculated on the basis of steady-state performance at constant power for the normal takeoff condition, where P_R = 1.18, $W\sqrt{\theta}/\delta A$ = 36 lb/ft^2/sec, and $\Delta\beta$ = -4.1°. The results show that for the specified distortions:

- Distortion angle—30° for the inlet total pressure distortion
- Distortion angle—145° for the exit static pressure distortion
- A 50°F total temperature increase over 50% of the fan face or overall of the fan face for 0.5 seconds would have the same result—i.e., a 2% thrust decrease.



Distortion angle

DIGITAL COMPUTER SIMULATION PROGRAM

DDA has prepared a program in the form of a deck of cards for use in calculating the steady-state performance of the Model PD370-30 and PD370-32 propulsion systems.

The program considers the propulsion system as an arrangement of power producers and thrusting units coupled together by shafting through a centrally mounted mixer gearbox, as shown in Figure 1.

The Model PD370-30 three-engine, three-fan system has two turbofan engines which are considered to be separate jet engines (i.e., primary and secondary streams exit from separate nozzles).

Model PD370-32 system turbofan engines are considered to be confluent-flow jet engines (i.e., primary and secondary streams are combined before exiting from jet nozzle). Mixing is accomplished by equal static pressures of the streams.

The remote fan and the two fans of the turbofan engines are identical Hamilton Standard variable-pitch fans of 62-inch tip diameter. The turboshaft engine and the two gas generators of the turbofan engines are Allison XT701 turboshaft engines.

With this program, the user may, for a given set of flight conditions, calculate steady-state performance by entering the proper values of the program input data.

Steady-state performance can be calculated for either vertical or conventional flight. Vertical flight performance is calculated with the remote fan producing vertical thrust and the turbofan engines configured to produce vertical thrust. Conventional flight performance is calculated with only the turbofans producing normal forward thrust.

Vertical flight performance calculations are performed under the following constraints:

- Equality of fan rotational speeds
- Equality of turbine inlet temperature—turbofan and turboshaft units
- Power balance in shafting
- Equality of lift thrust—turbofan and remote fan units (nonattitude control only)

With the turboshaft engine inoperative, sufficient power is transferred through the shafting to drive the remote fan. All fan pitch angles are adjusted to achieve equal thrust or control thrust.

Normally, vertical flight performance is calculated at "intermediate" power level. However, the user can request a thrust level for any vertical flight operational mode. This thrust must be lower than that obtained at the intermediate power. The program will calculate the fan pitch angles. A "contingency" power level greater than intermediate is also available. The performance calculated at this power level is to be used for information purposes only. The intermediate power level is the qualified rating of the XT701-AD-700 engine. Any higher rating, such as contingency, would require development and testing beyond the scope of the base-line Research and Technology Aircraft development program.

The system performance during conventional flight is calculated with the turboshaft engine unpowered and disengaged and the remote fan disengaged. The turbofan engines are configured to produce normal forward thrust and are considered equal in all respects. The center mixing gear is still coupled to the system. Thus, the calculation becomes one of a conventional turbofan with the addition of a small amount of power flowing to the center gear from the cross shaft. This power is composed of the center gearing losses and any requested customer power extraction from the center gearbox.

Predefined power levels of "intermediate" and "maximum continuous," and also lower undefined power levels are available for the study of climb and cruise performance in the conventional flight mode.

Certain temperature and rotational speed limiters are built into the program. At any flight condition and operational mode, system performance is limited by whichever of these limiters is in effect. This is in accordance with standard procedure for engine performance calculations.

Additionally, for this propulsion system, the fan pitch angle is limited to within a range bounded by a minimum (negative pitch) and a maximum (positive pitch). The minimum pitch setting defined analytically to date effectively limits the torque moment available for roll and pitch maneuvers in this analytical performance model.

The card deck as delivered to users calculates the performance of an uninstalled propulsion system. The user can input his own installation factors, such as inlet losses, nozzle coefficients, and flow bleeds and power extractions. The details of the method of entering these and other inputs into the program are described in a users manual report which accompanies each card deck.

Fan rotational speed is fixed at a preset value for all vertical flight calculations. Equality of lift thrust from the remote fan and the two turbofan units is achieved by adjustment of the individual fan pitch angles, along with power transfer within the shafting for delivery of required power to each lift unit. Gearing losses are considered during the calculation of power transfer.

The thrust of a turbofan is calculated as the total net thrust, the sum of the primary and secondary thrusts. However, the residual thrust of the turboshaft engine is not considered during thrust balancing.

The system performance can be calculated during vertical modes of level flight and pitch and roll attitude control. For each of these modes, performance can be calculated with all engines operative or with one engine inoperative. Either a turbofan or the turboshaft engine can be inoperative. Performance can be calculated either "dry" or with a preset amount of water-alcohol injection augmentation at each engine's compressor inlet. The performance with water-alcohol is for information purposes only. Water-alcohol is not part of the XT701-AD-700 engine and would require development and testing beyond the scope of the base-line Research and Development Aircraft development program.

Attitude control performance is calculated on the basis of a thrust increment which is input by the user. For roll control, this increment is applied to one of the turbofan engines by adjustment of its fan pitch angle. The fan pitch angles of the opposite turbofan engine and the remote fan are then adjusted until a solution is achieved which simultaneously balances power transferred through the shafting and causes the thrust of the remote fan to be an average of the two turbofan thrusts. Thus, no pitching moment exists.

For pitch control, the input thrust increment is applied to the remote fan. The fan pitch angles of the turbofan engines are then adjusted until a solution is achieved which simultaneously balances power transferred through the shafting and maintains equality of the turbofan engine thrust. Thus, no roll moment occurs during pitch control.

When a turbofan engine is inoperative, power is transferred through the shafting to sustain the fan of the inoperative engine. Again, fan pitch angles of both turbofan engines and the remote fan are adjusted until thrust equality of the three units or the proper roll or pitch control thrust is achieved.

TABULATED PERFORMANCE DATA

Propulsion system performance data for the following conditions listed is presented in Tables XIV through XXVII.

- **Uninstalled**

	Altitude (ft)	M_N
Conventional flight	0	0, 0.2, 0.4, 0.6, 0.8
Intermediate power	10,000	0, 0.2, 0.4, 0.6, 0.8
	20,000	0.2, 0.4, 0.6
	30,000	0.4, 0.6, 0.8
	36,089	0.6, 0.8
Intermediate power and below	0	0
(SFC hooks)	10,000	0.4
	20,000	0.6
	36,089	0.6

Vertical flight, 3E-3F	Level flight, std day, dry
	Level flight, 90°F day, dry
	Roll control, 90°F day, dry
	Pitch control, 90°F day, dry
Vertical flight, 2E-3F, turbofan out	Level flight, std day, dry
	Level flight, 90°F day, dry
	Roll control, 90°F day, dry
	Level flight, std day, wet
	Level flight, 90°F day, wet
	Roll control, 90°F day, wet
Vertical flight, 2E-3F, turboshaft out	Level flight, std day, dry
	Level flight, 90°F day, dry
	Level flight, 90°F day, wet

● Installed (2 sets)
(Boeing and McDonnell factors)

	Altitude (ft)	M_N
Conventional flight	0	0, 0.2, 0.4, 0.6, 0.8
Intermediate power	10,000	0, 0.2, 0.4, 0.6, 0.8
	20,000	0.2, 0.4, 0.6
	30,000	0.4, 0.6, 0.8
	36,089	0.6, 0.8
Intermediate power and below	0	0
(SFC hooks)	10,000	0.4
	20,000	0.6
	36,089	0.6
Vertical flight, 3E-3F	Level flight, 90°F day, dry	
	Roll control, 90°F day, dry	
Vertical flight, 2E-3F, turbofan out	Level flight, 90°F day, dry	
	Roll control, 90°F day, dry	
	Level flight, 90°F day, wet	
	Roll control, 90°F day, wet	

Thrust from the turboshaft engine is not considered in equal thrust distribution and is not added into the total thrust of a system.

TABLE XIV. PD370-30 PERFORMANCE (UNINSTALLED)
(Conventional flight, intermediate power)

MACH	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
						0. FT ALTITUDE									
0.0	684.4	103.4	1.215	47.2	1565.	16.13	1016.	638.2	552.	17.68	11396.	12412.	12412.	3521.	TF
0.2	676.8	103.1	1.226	48.6	1582.	16.24	760.	645.5	558.	18.34	8186.	8945.	13756.	3700.	TF
0.4	656.2	101.9	1.243	52.3	1613.	16.52	569.	670.1	574.	20.21	6576.	7145.	17156.	4099.	TF
0.6	641.8	100.0	1.238	56.5	1614.	16.84	336.	735.4	595.	23.01	5548.	5885.	22349.	4423.	TF
0.8	632.3	97.5	1.221	62.1	1603.	17.28	87.	846.8	623.	27.11	4906.	4993.	30190.	4779.	TF
						10000. FT ALTITUDE									
0.0	701.7	107.3	1.227	34.9	1489.	11.19	765.	465.8	516.	12.27	8245.	9010.	9010.	2503.	TF
0.2	694.1	106.9	1.240	36.0	1509.	11.28	589.	471.3	522.	12.76	6007.	6596.	9989.	2642.	TF
0.4	671.7	105.6	1.260	38.6	1538.	11.49	459.	488.3	537.	14.09	4883.	5341.	12389.	2919.	TF
0.6	654.7	103.6	1.258	41.9	1542.	11.75	308.	533.9	557.	16.07	4165.	4473.	16024.	3173.	TF
0.8	644.2	101.0	1.244	46.4	1543.	12.14	163.	613.6	584.	19.01	3774.	3937.	21595.	3500.	TF
						20000. FT ALTITUDE									
0.2	706.6	110.0	1.251	25.9	1434.	7.62	443.	332.6	486.	8.60	4200.	4643.	6951.	1829.	TF
0.4	689.9	109.8	1.282	28.1	1477.	7.81	377.	347.6	501.	9.58	3557.	3934.	8771.	2078.	TF
0.6	670.0	107.7	1.282	30.6	1484.	8.02	287.	378.4	520.	10.95	3072.	3359.	11257.	2273.	TF
						30000. FT ALTITUDE									
0.4	690.9	110.0	1.284	19.1	1365.	5.06	250.	234.3	461.	6.19	2310.	2560.	5689.	1296.	TF
0.6	679.1	110.0	1.297	21.3	1404.	5.26	224.	257.7	481.	7.15	2101.	2325.	7495.	1512.	TF
0.8	671.8	109.4	1.298	24.3	1432.	5.57	211.	297.4	506.	8.55	2030.	2241.	10186.	1768.	TF
						36089. FT ALTITUDE									
0.6	679.1	110.0	1.297	16.5	1334.	3.97	172.	199.0	456.	5.38	1580.	1752.	5638.	1108.	TF
0.8	674.1	110.0	1.302	19.0	1366.	4.21	170.	230.2	480.	6.45	1550.	1720.	7710.	1316.	TF

TABLE XV. PD370-30 PERFORMANCE (UNINSTALLED)

(Conventional flight, intermediate power and below)

MACH	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
0. FT ALTITUDE															
0.0	684.4	103.4	1.215	47.2	1565.	16.13	1016.	638.2	552.	17.68	11396.	12412.	12412.	3521.	TF
0.0	684.4	103.4	1.215	47.2	1565.	16.13	1016.	638.2	552.	17.68	11395.	12410.	12410.	3521.	TF
0.0	620.2	92.6	1.175	42.2	1459.	15.77	763.	578.7	546.	17.11	9338.	10101.	10101.	2743.	TF
0.0	543.7	80.7	1.132	37.1	1352.	15.46	549.	507.1	539.	16.52	7157.	7706.	7706.	2042.	TF
0.0	445.9	66.2	1.088	30.6	1244.	15.17	342.	415.7	533.	15.91	4809.	5152.	5152.	1373.	TF
0.0	428.3	63.7	1.081	29.4	1227.	15.12	312.	399.2	532.	15.81	4436.	4748.	4748.	1273.	TF
0.0	409.5	61.0	1.074	28.1	1210.	15.08	280.	381.7	531.	15.71	4054.	4334.	4334.	1172.	TF
0.0	389.4	58.1	1.067	26.7	1194.	15.04	248.	363.0	529.	15.61	3666.	3914.	3914.	1072.	TF
0.0	368.9	55.1	1.060	25.3	1177.	14.99	217.	343.9	528.	15.52	3287.	3504.	3504.	976.	TF
10000. FT ALTITUDE															
0.4	671.8	105.6	1.260	38.6	1538.	11.49	458.	488.4	537.	14.09	4883.	5341.	12389.	2919.	TF
0.4	671.8	105.6	1.260	38.6	1538.	11.49	458.	488.4	537.	14.09	4882.	5341.	12389.	2919.	TF
0.4	648.2	100.1	1.234	36.6	1481.	11.31	358.	471.8	533.	13.80	4337.	4695.	11497.	2586.	TF
0.4	597.8	91.0	1.179	32.3	1360.	10.96	177.	436.5	525.	13.20	3250.	3427.	9700.	1942.	TF
0.4	529.3	77.0	1.115	26.5	1214.	10.63	20.	388.0	516.	12.49	1972.	1992.	7545.	1274.	TF
0.4	462.2	62.6	1.062	21.4	1099.	10.40	-68.	340.8	508.	11.92	961.	893.	5743.	792.	TF
0.4	451.0	60.1	1.054	20.4	1081.	10.37	-77.	333.0	507.	11.83	814.	737.	5469.	722.	TF
0.4	440.7	57.9	1.047	19.5	1067.	10.35	-84.	325.9	506.	11.75	689.	605.	5230.	664.	TF
0.4	431.2	55.9	1.041	18.6	1053.	10.32	-90.	319.4	505.	11.69	575.	485.	5010.	609.	TF
0.4	422.4	54.0	1.035	17.7	1039.	10.30	-94.	313.4	505.	11.62	475.	381.	4813.	558.	TF
20000. FT ALTITUDE															
0.6	670.0	107.7	1.282	30.6	1484.	8.02	287.	378.4	520.	10.95	3072.	3359.	11257.	2273.	TF
0.6	670.0	107.7	1.282	30.6	1484.	8.02	287.	378.4	520.	10.95	3072.	3359.	11257.	2273.	TF
0.6	663.6	106.0	1.272	30.0	1458.	7.94	250.	375.1	518.	10.86	2946.	3195.	11018.	2161.	TF
0.6	652.9	103.1	1.254	29.0	1420.	7.84	198.	369.5	516.	10.71	2742.	2940.	10637.	1999.	TF
0.6	635.0	98.2	1.226	27.5	1366.	7.69	128.	360.1	512.	10.47	2415.	2542.	10028.	1768.	TF
0.6	617.4	94.4	1.200	26.0	1312.	7.55	65.	350.8	508.	10.25	2111.	2175.	9453.	1552.	TF
0.6	581.5	86.5	1.150	22.9	1204.	7.32	-38.	331.9	501.	9.83	1530.	1493.	8347.	1162.	TF
0.6	527.1	71.9	1.083	18.4	1053.	7.07	-123.	303.1	492.	9.26	758.	635.	6849.	698.	TF
36089. FT ALTITUDE															
0.6	679.1	110.0	1.297	16.5	1333.	3.96	171.	199.0	456.	5.38	1580.	1751.	5637.	1107.	TF
0.6	679.1	110.0	1.297	16.5	1333.	3.96	171.	199.0	456.	5.38	1580.	1751.	5637.	1108.	TF
0.6	668.4	107.2	1.279	16.0	1289.	3.90	138.	196.2	453.	5.30	1474.	1612.	5437.	1014.	TF
0.6	652.3	102.8	1.253	15.2	1238.	3.82	99.	191.8	449.	5.19	1324.	1423.	5155.	902.	TF
0.6	644.0	100.4	1.240	14.9	1217.	3.79	83.	189.5	448.	5.14	1250.	1333.	5018.	855.	TF
0.6	634.1	98.0	1.225	14.4	1191.	3.75	64.	186.8	446.	5.08	1164.	1228.	4856.	798.	TF
0.6	622.6	95.5	1.208	13.9	1160.	3.70	44.	183.6	444.	5.01	1067.	1110.	4673.	734.	TF
0.6	594.6	89.7	1.168	12.6	1086.	3.60	1.	176.0	439.	4.84	841.	843.	4245.	591.	TF
0.6	525.0	71.3	1.080	9.7	919.	3.44	-59.	156.8	429.	4.48	354.	295.	3299.	318.	TF

TABLE XVI. PD370-30 PERFORMANCE (UNINSTALLED)
(Vertical flight, sea level static, intermediate power, 3 engines, 3 fans)

PITCH DEG	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
					LEVEL FLIGHT		518.7 R	DAY	DRY						
2.4	708.8	103.5	1.232	50.5	1668.	16.46	1240.	659.4	555.	17.90	12193.	13433.	13433.	4173.	TF
0.0	44.6	103.5	0.0	45.7	1671.	15.27	648.	0.0	0.	0.0	0.	648.	648.	3853.	TS
3.5	721.9	103.5	1.236	0.0	0.	0.0	0.	721.9	556.	17.93	13425.	13425.	13425.	0.	LF
					LEVEL FLIGHT		549.5 R	DAY	DRY						
1.1	682.2	100.6	1.214	46.3	1684.	16.19	1055.	617.5	585.	17.65	11318.	12373.	12373.	3766.	TF
0.0	43.8	100.6	0.0	43.4	1683.	15.22	593.	0.0	0.	0.0	0.	593.	593.	3609.	TS
2.1	693.6	100.6	1.216	0.0	0.	0.0	0.	673.9	586.	17.66	12368.	12368.	12368.	0.	LF
					ROLL CONTROL		549.5 R	DAY	DRY						
6.9	734.1	100.6	1.254	46.2	1685.	16.18	1051.	668.0	592.	18.21	13297.	14348.	14348.	3749.	TFH
-5.4	609.9	100.6	1.166	46.1	1685.	16.18	1046.	547.5	577.	16.99	8886.	9932.	9932.	3762.	TFL
0.0	43.8	100.6	0.0	43.4	1683.	15.22	593.	0.0	0.	0.0	0.	593.	593.	3609.	TS
1.4	687.3	100.6	1.212	0.0	0.	0.0	0.	667.8	585.	17.60	12142.	12142.	12142.	0.	LF
					PITCH CONTROL		549.5 R	DAY	DRY						
-2.1	647.9	100.6	1.190	46.3	1684.	16.19	1053.	584.2	581.	17.32	10123.	11176.	11176.	3768.	TF
0.0	43.8	100.6	0.0	43.4	1683.	15.22	593.	0.0	0.	0.0	0.	593.	593.	3609.	TS
7.3	741.7	100.6	1.250	0.0	0.	0.0	0.	720.6	593.	18.13	14205.	14205.	14205.	0.	LF

TABLE XVII. PD370-30 PERFORMANCE (UNINSTALLED)

(Vertical flight, sea level static, intermediate power, 2 engines, 3 fans) (turbofan out)

PITCH DEG	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
					LEVEL FLIGHT		518.7 R	DAY	DRY						
-7.1	604.2	103.5	1.161	5).0	1669.	16.43	1215.	555.3	545.	16.92	8627.	9841.	9841.	4149.	TF
0.0	44.6	103.5	0.0	45.7	1671.	15.27	648.	0.0	0.	0.0	0.	648.	648.	3853.	TS
-5.9	619.2	103.5	1.170	0.C	0.	0.0	0.	619.2	547.	17.02	9846.	9846.	9846.	0.	LF
-6.8	596.3	103.5	1.185	0.C	0.	0.0	0.	592.6	548.	17.25	9841.	9841.	9841.	0.	EOF
					LEVEL FLIGHT		549.5 R	DAY	DRY						
-7.6	581.4	100.6	1.148	45.5	1685.	16.16	1037.	519.9	575.	16.74	7997.	9034.	9034.	3749.	TF
0.0	43.8	100.6	0.0	43.4	1682.	15.22	593.	0.0	0.	0.0	0.	593.	593.	3608.	TS
-6.7	593.3	100.6	1.156	0.C	0.	0.0	0.	576.4	577.	16.82	9036.	9036.	9036.	0.	LF
-7.5	571.3	100.6	1.169	0.0	C.	0.0	0.	551.7	578.	17.02	9032.	9)32.	9032.	0.	EOF
					RCLL CCNTROL		549.5 R	DAY	DRY						
0.6	677.0	100.6	1.210	46.3	1684.	16.19	1056.	612.4	584.	17.6)	11132.	12187.	12187.	3769.	TF
0.0	43.8	100.6	0.0	43.4	1682.	15.22	593.	0.0	0.	0.0	0.	593.	593.	3608.	TS
-6.8	591.3	100.6	1.155	0.0	0.	0.0	0.	574.5	577.	16.81	8977.	8977.	8977.	0.	LF
-16.8	457.5	100.6	1.106	0.0	).	0.0	0.	441.1	569.	16.15	5766.	5766.	5766.	C.	EOF

TABLE XVIII. PD370-30 PERFORMANCE (UNINSTALLED)

(Vertical flight, sea level static, intermediate power, 2 engines, 3 fans) (turbofan out)

PITCH DEG	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
					LEVEL FLIGHT		518.7 R	DAY	WET						
-6.0	618.4	103.5	1.168	53.2	1658.	16.65	1364.	516.4	546.	17.01	8992.	10356.	10356.	4513.	TF
0.0	44.8	107.2	0.0	47.2	1665.	15.31	691.	0.0	0.	0.0	0.	691.	691.	4056.	TS
-4.7	634.7	103.5	1.179	0.0	0.	0.0	0.	634.7	548.	17.15	10357.	10357.	10357.	0.	LF
-5.5	611.6	103.5	1.195	0.0	0.	0.0	0.	607.7	550.	17.39	10356.	10356.	10356.	0.	EOF
					LEVEL FLIGHT		549.5 R	DAY	WET						
-5.6	608.6	100.6	1.162	51.6	1663.	16.54	1288.	540.8	577.	16.93	8676.	9963.	9963.	4329.	TF
0.[illegible]	44.8	106.8	0.0	46.3	1668.	15.28	665.	0.0	0.	0.0	0.	665.	665.	3932.	TS
-4.[illegible]	622.8	100.6	1.172	0.0	0.	0.0	0.	605.1	579.	17.05	9963.	9963.	9963.	0.	LF
-5.[illegible]	600.1	100.6	1.187	0.0	0.	0.0	0.	579.2	581.	17.28	9963.	9963.	9963.	0.	EOF
					ROLL CONTROL		549.5 R	DAY	WET						
5.0	719.9	100.6	1.237	52.8	1660.	16.62	1341.	647.8	589.	17.98	12490.	13831.	13831.	4405.	TF
0.0	44.8	106.8	0.0	46.3	1668.	15.28	666.	0.0	0.	0.0	0.	666.	666.	3934.	TS
-4.9	616.6	100.6	1.169	0.0	0.	0.0	0.	599.1	578.	17.00	9766.	9766.	9766.	0.	LF
-17.0	455.4	100.6	1.105	0.0	0.	0.0	0.	438.6	569.	16.14	5704.	5704.	5704.	0.	EOF

TABLE XIX. PD370-30 PERFORMANCE (UNINSTALLED)

(Vertical flight, sea level static, intermediate power, 2 engines, 3 fans) (turboshaft out)

PITCH DEG	WCOR LB/SEC	NCOR %	FPR	WP LB/SFC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
					LEVEL FLIGHT		518.7 R	DAY	DRY						
-5.6	622.8	103.5	1.172	50.1	1668.	16.44	1221.	573.7	546.	17.08	9210.	10431.	10431.	4159.	TF
-4.5	637.3	103.5	1.181	0.0	0.	0.0	0.	637.3	548.	17.17	10432.	10432.	10432.	0.	LF
					LEVEL FLIGHT		549.5 R	DAY	DRY						
-6.7	592.7	100.6	1.156	46.0	1685.	16.17	1040.	530.9	576.	16.84	8357.	9397.	9397.	3752.	TF
-5.8	605.0	100.6	1.162	0.0	0.	0.0	0.	587.8	578.	16.91	9396.	9396.	9396.	0.	LF
					LEVEL FLIGHT		549.5 R	DAY	WET						
-3.7	631.4	100.6	1.176	51.9	1662.	16.56	1302.	562.6	579.	17.12	9388.	10690.	10690.	4352.	TF
-2.5	645.1	100.6	1.185	0.0	0.	0.0	0.	626.8	581.	17.23	10691.	10691.	10691.	0.	LF

TABLE XX. PD370-30 PERFORMANCE (BOEING INSTALLED)

(Conventional flight, intermediate power)

MACH	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
0. FT ALTITUDE															
0.0	682.5	103.5	1.220	47.3	1579.	16.15	1026.	630.7	553.	17.61	11055.	12081.	12081.	3579.	TF
0.2	676.3	103.1	1.227	48.7	1588.	16.25	762.	643.6	558.	18.32	8020.	8782.	13580.	3726.	TF
0.4	655.7	101.9	1.243	52.3	1618.	16.53	571.	668.1	574.	20.18	6397.	6968.	16953.	4122.	TF
0.6	641.6	100.0	1.238	56.5	1617.	16.85	338.	733.6	595.	22.96	5350.	5688.	22114.	4440.	TF
0.8	632.3	97.5	1.221	62.1	1606.	17.28	86.	845.1	623.	27.06	4679.	4765.	29913.	4794.	TF
10000. FT ALTITUDE															
0.0	699.9	107.3	1.232	34.9	1504.	11.21	774.	460.5	517.	12.22	8002.	8776.	8776.	2546.	TF
0.2	693.7	106.9	1.241	36.1	1516.	11.30	595.	469.9	522.	12.74	5891.	6485.	9869.	2669.	TF
0.4	671.3	105.6	1.261	38.7	1544.	11.51	463.	486.9	537.	14.07	4757.	5219.	12249.	2942.	TF
0.6	654.6	103.6	1.258	41.9	1547.	11.76	311.	532.5	557.	16.04	4026.	4337.	15863.	3193.	TF
0.8	644.3	101.0	1.244	46.5	1547.	12.15	166.	612.3	584.	18.97	3613.	3780.	21405.	3518.	TF
20000. FT ALTITUDE															
0.2	706.2	110.2	1.252	26.0	1443.	7.63	449.	331.6	486.	8.58	4119.	4568.	6870.	1853.	TF
0.4	689.6	109.8	1.283	28.2	1486.	7.82	382.	346.7	501.	9.56	3470.	3852.	8677.	2102.	TF
0.6	669.9	107.7	1.282	30.7	1492.	8.03	292.	377.5	520.	10.93	2976.	3268.	11150.	2295.	TF
30000. FT ALTITUDE															
0.4	690.7	110.0	1.284	19.2	1380.	5.07	256.	233.6	461.	6.18	2253.	2510.	5632.	1321.	TF
0.6	679.0	110.0	1.297	21.4	1416.	5.28	231.	257.1	481.	7.14	2038.	2269.	7428.	1535.	TF
0.8	672.0	109.4	1.297	24.4	1440.	5.58	218.	296.7	506.	8.54	1956.	2174.	10105.	1788.	TF
36089. FT ALTITUDE															
0.6	679.1	110.0	1.297	16.6	1352.	3.98	179.	198.5	456.	5.37	1532.	1712.	5590.	1133.	TF
0.8	674.3	110.0	1.302	19.1	1378.	4.23	178.	229.7	480.	6.43	1493.	1671.	7652.	1338.	TF

TABLE XXI. PD370-30 PERFORMANCE (BOEING INSTALLED)

(Conventional flight, intermediate power and below)

MACH	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
						0. FT ALTITUDE									
0.0	682.5	103.5	1.220	47.3	1579.	16.15	1026.	630.7	553.	17.61	11055.	12081.	12081.	3579.	TF
0.0	682.5	103.5	1.220	47.3	1579.	16.15	1027.	630.7	553.	17.61	11056.	12083.	12083.	3579.	TF
0.0	615.3	92.4	1.178	42.2	1471.	15.78	768.	568.9	546.	17.02	8961.	9728.	9728.	2779.	TF
0.0	535.6	80.4	1.135	37.1	1361.	15.47	550.	494.7	540.	16.43	6762.	7312.	7312.	2062.	TF
0.0	432.4	65.8	1.089	30.5	1251.	15.16	339.	398.9	533.	15.80	4382.	4721.	4721.	1379.	TF
0.0	413.8	63.3	1.083	29.3	1234.	15.13	312.	381.4	532.	15.71	4017.	4329.	4329.	1283.	TF
0.0	394.4	60.6	1.076	28.1	1219.	15.08	282.	363.4	531.	15.62	3645.	3927.	3927.	1186.	TF
0.0	373.5	57.7	1.068	26.7	1202.	15.04	251.	344.0	530.	15.52	3266.	3517.	3517.	1089.	TF
						10000. FT ALTITUDE									
0.4	671.4	105.6	1.261	38.7	1544.	11.50	462.	487.0	537.	14.07	4756.	5218.	12249.	2942.	TF
0.4	671.3	105.6	1.261	38.7	1544.	11.51	463.	486.9	537.	14.07	4757.	5220.	12249.	2942.	TF
0.4	647.7	100.1	1.234	36.7	1487.	11.32	362.	470.3	533.	13.77	4213.	4576.	11358.	2607.	TF
0.4	597.0	90.9	1.180	32.4	1366.	10.97	181.	434.9	525.	13.18	3135.	3316.	9568.	1963.	TF
0.4	528.1	76.9	1.115	27.1	1220.	10.64	23.	386.1	516.	12.47	1871.	1894.	7424.	1293.	TF
0.4	460.9	62.5	1.062	21.7	1106.	10.41	-65.	338.8	508.	11.90	876.	811.	5638.	814.	TF
0.4	450.0	60.0	1.054	20.7	1088.	10.38	-77.	331.2	507.	11.81	731.	654.	5366.	744.	TF
0.4	439.5	57.8	1.047	19.8	1074.	10.36	-82.	323.9	506.	11.73	608.	527.	5129.	687.	TF
0.4	430.2	55.7	1.041	18.9	1060.	10.33	-89.	317.5	505.	11.66	494.	405.	4910.	632.	TF
0.4	421.2	53.8	1.035	18.1	1046.	10.31	-93.	311.4	505.	11.60	394.	301.	4711.	580.	TF
						20000. FT ALTITUDE									
0.6	669.9	107.7	1.282	30.7	1492.	8.03	292.	377.5	520.	10.93	2976.	3268.	11150.	2295.	TF
0.6	669.9	107.7	1.282	30.7	1492.	8.03	292.	377.5	520.	10.93	2976.	3268.	11149.	2295.	TF
0.6	663.4	106.0	1.272	30.1	1464.	7.96	254.	374.2	518.	10.84	2850.	3104.	10909.	2180.	TF
0.6	652.7	103.1	1.254	29.1	1426.	7.85	203.	368.6	516.	10.69	2648.	2850.	10529.	2018.	TF
0.6	634.8	98.2	1.226	27.6	1373.	7.70	132.	359.1	512.	10.45	2323.	2455.	9922.	1787.	TF
0.6	617.1	94.4	1.200	26.1	1319.	7.56	69.	349.8	508.	10.23	2021.	2090.	9350.	1571.	TF
0.6	581.1	86.5	1.150	23.0	1212.	7.33	-33.	330.8	501.	9.81	1446.	1413.	8249.	1181.	TF
0.6	526.6	71.8	1.082	18.6	1061.	7.08	-120.	301.9	492.	9.24	684.	563.	6759.	717.	TF
						36089. FT ALTITUDE									
0.6	679.1	110.0	1.297	16.6	1352.	3.98	179.	198.5	456.	5.37	1532.	1711.	5589.	1133.	TF
0.6	679.1	110.0	1.297	16.6	1352.	3.98	179.	198.5	456.	5.37	1532.	1711.	5589.	1132.	TF
0.6	668.5	107.2	1.279	16.1	1302.	3.91	145.	195.7	453.	5.29	1426.	1571.	5389.	1036.	TF
0.6	652.3	102.8	1.253	15.4	1251.	3.83	106.	191.2	449.	5.18	1277.	1383.	5108.	924.	TF
0.6	644.0	100.4	1.240	15.0	1230.	3.80	89.	189.0	448.	5.13	1204.	1294.	4971.	876.	TF
0.6	634.0	98.0	1.224	14.6	1204.	3.76	71.	186.2	446.	5.07	1118.	1189.	4810.	819.	TF
0.6	622.5	95.4	1.207	14.1	1173.	3.72	50.	183.1	444.	5.00	1022.	1071.	4626.	755.	TF
0.6	594.4	89.6	1.167	12.8	1100.	3.61	7.	175.4	439.	4.83	799.	805.	4200.	612.	TF
0.6	524.7	71.3	1.080	9.9	935.	3.45	-56.	156.2	429.	4.47	317.	261.	3258.	338.	TF

TABLE XXII. PD370-30 PERFORMANCE (BOEING INSTALLED)

(Vertical flight, sea level static, intermediate power, 3 engines, 3 fans)

PITCH DEG	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
					LEVEL FLIGHT		549.5 R DAY		DRY						
0.7	674.7	100.6	1.215	45.9	1685.	16.17	1037.	605.3	585.	17.54	10803.	11840.	11840.	3738.	TF
0.0	43.8	100.6	0.0	43.0	1685.	15.21	582.	0.0	0.	0.0	0.	582.	582.	3573.	TS
1.6	686.3	100.6	1.218	0.0	0.	0.0	0.	661.5	586.	17.55	11838.	11838.	11838.	0.	LF
					ROLL CONTROL		549.5 R DAY		DRY						
6.9	729.1	100.6	1.256	46.1	1686.	16.17	1041.	657.6	592.	18.10	12803.	13844.	13844.	3736.	TFH
-6.0	599.2	100.6	1.167	45.7	1687.	16.15	1026.	532.9	578.	16.87	8359.	9385.	9385.	3729.	TFL
0.0	43.8	100.6	0.0	43.0	1685.	15.21	581.	0.0	0.	0.0	0.	581.	581.	3573.	TS
1.0	680.1	100.6	1.214	0.0	0.	0.0	0.	655.5	585.	17.49	11621.	11621.	11621.	0.	LF

TABLE XXIII. PD370-30 PERFORMANCE (BOEING INSTALLED)

(Vertical flight, sea level static, intermediate power, 2 engines, 3 fans) (turbofan out)

PITCH DEG	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
						LEVEL FLIGHT	549.5 R	DAY	DRY						
-8.1	571.9	100.6	1.151	45.5	1686.	16.14	1020.	506.6	575.	16.65	7572.	8592.	8592.	3720.	TF
0.0	43.8	100.6	0.0	43.0	1684.	15.21	581.	0.0	0.	0.0	0.	581.	581.	3572.	TS
-7.1	584.8	100.6	1.158	0.0	0.	0.0	0.	563.6	577.	16.73	8598.	8598.	8598.	0.	LF
-7.9	563.1	100.6	1.171	0.0	0.	0.0	0.	539.3	579.	16.92	8590.	8590.	8590.	0.	EOF
						ROLL CONTROL	549.5 R	DAY	DRY						
-3.1	667.1	100.6	1.210	46.0	1685.	16.17	1039.	598.0	584.	17.47	10561.	11600.	11600.	3742.	TF
0.0	43.8	100.6	0.0	43.0	1684.	15.21	581.	0.0	0.	0.0	0.	581.	581.	3572.	TS
-7.2	583.3	100.6	1.157	0.0	0.	0.0	0.	562.2	577.	16.72	8552.	8552.	8552.	0.	LF
-17.5	451.9	100.6	1.111	0.0	0.	0.0	0.	432.1	570.	16.10	5507.	5507.	5507.	0.	EOF
						LEVEL FLIGHT	549.5 R	DAY	WET						
-6.1	599.6	100.6	1.163	51.1	1664.	16.50	1262.	527.9	577.	16.82	8224.	9485.	9485.	4289.	TF
0.0	44.8	106.8	0.0	45.9	1670.	15.27	652.	0.0	0.	0.0	0.	652.	652.	3895.	TS
-4.8	614.1	100.6	1.174	0.0	0.	0.0	0.	591.9	579.	16.95	9484.	9484.	9484.	0.	LF
-5.5	591.7	100.6	1.198	0.0	0.	0.0	0.	566.5	581.	17.16	9482.	9482.	9482.	0.	EOF
						ROLL CONTROL	549.5 R	DAY	WET						
4.2	709.8	100.6	1.236	52.4	1661.	16.59	1319.	632.9	588.	17.83	11855.	13174.	13174.	4374.	TF
3.3	44.8	106.8	0.0	45.8	1670.	15.27	652.	0.0	0.	0.0	0.	652.	652.	3897.	TS
-5.1	610.3	100.6	1.172	0.0	0.	0.0	0.	588.2	579.	16.92	9367.	9367.	9367.	0.	LF
-16.8	454.4	100.6	1.112	0.0	0.	0.0	0.	434.1	570.	16.11	5561.	5561.	5561.	0.	EOF

TABLE XXIV. PD370-30 PERFORMANCE (MCDONNELL INSTALLATION)

(Conventional flight, intermediate power)

MACH	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
						0. FT ALTITUDE									
0.0	681.3	103.5	1.223	47.1	1589.	16.15	1022.	627.0	553.	17.57	10976.	11998.	11998.	3596.	TF
0.2	675.0	103.1	1.229	48.5	1598.	16.25	762.	639.3	558.	18.28	7949.	8711.	13478.	3747.	TF
0.4	654.9	101.9	1.244	52.0	1625.	16.52	564.	665.3	574.	20.13	6358.	6921.	16863.	4123.	TF
0.6	641.0	100.0	1.238	56.2	1623.	16.83	329.	730.7	595.	22.90	5305.	5634.	21994.	4434.	TF
0.8	632.2	97.5	1.221	61.7	1612.	17.26	77.	841.6	623.	26.95	4608.	4684.	29726.	4788.	TF
						10000. FT ALTITUDE									
0.0	698.9	107.3	1.235	34.7	1514.	11.20	768.	458.0	517.	12.20	7952.	8720.	8720.	2556.	TF
0.2	692.7	106.9	1.244	35.9	1526.	11.29	589.	467.1	522.	12.71	5841.	6430.	9794.	2677.	TF
0.4	670.6	105.6	1.262	38.4	1550.	11.49	454.	485.0	537.	14.04	4729.	5183.	12184.	2940.	TF
0.6	653.9	103.6	1.258	41.6	1553.	11.74	303.	530.5	557.	16.00	3995.	4298.	15776.	3186.	TF
0.8	644.1	101.0	1.244	46.1	1552.	12.12	156.	609.9	584.	18.89	3563.	3718.	21268.	3508.	TF
						20000. FT ALTITUDE									
0.2	705.1	110.0	1.254	25.8	1452.	7.62	441.	329.7	486.	8.56	4087.	4527.	6816.	1852.	TF
0.4	688.9	109.8	1.284	28.0	1492.	7.81	374.	345.4	501.	9.54	3453.	3827.	8633.	2098.	TF
0.6	669.4	107.7	1.283	30.4	1497.	8.02	283.	376.2	520.	10.90	2955.	3238.	11089.	2288.	TF
						30000. FT ALTITUDE									
0.4	689.8	110.0	1.285	18.9	1383.	5.06	248.	232.8	461.	6.17	2244.	2492.	5600.	1312.	TF
0.6	678.5	110.0	1.298	21.2	1420.	5.26	221.	256.3	481.	7.12	2025.	2246.	7385.	1525.	TF
0.8	671.6	109.4	1.298	24.1	1446.	5.56	207.	295.6	506.	8.50	1934.	2140.	10035.	1778.	TF
						36089. FT ALTITUDE									
0.6	678.5	110.0	1.298	16.4	1351.	3.96	170.	197.9	456.	5.35	1523.	1693.	5555.	1120.	TF
0.8	673.8	110.0	1.302	18.8	1363.	4.20	167.	228.8	480.	6.41	1477.	1643.	7595.	1328.	TF

TABLE XXV. PD370-30 PERFORMANCE (MCDONNELL INSTALLATION)

(Conventional flight, intermediate power and below)

MACH	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FAT LB	FGT LB	WF LB/HR	
0. FT ALTITUDE															
0.0	681.3	103.5	1.223	47.1	1589.	16.15	1022.	627.0	553.	17.57	10976.	11998.	11998.	3596.	TF
0.0	677.8	102.8	1.220	46.8	1583.	16.13	1007.	623.7	553.	17.54	10863.	11869.	11869.	3548.	TF
0.0	612.4	92.4	1.180	42.0	1481.	15.77	763.	563.8	547.	16.99	8856.	9618.	9618.	2790.	TF
0.0	530.4	80.3	1.136	36.7	1369.	15.45	542.	487.9	540.	16.39	6619.	7161.	7161.	2060.	TF
0.0	424.1	65.6	1.090	29.9	1259.	15.15	331.	389.4	533.	15.76	4207.	4538.	4538.	1369.	TF
0.0	405.5	63.1	1.083	28.7	1244.	15.11	302.	372.2	532.	15.66	3846.	4147.	4147.	1273.	TF
0.0	385.7	60.4	1.076	27.4	1228.	15.07	271.	353.9	531.	15.57	3478.	3749.	3749.	1175.	TF
0.0	364.4	57.5	1.069	26.1	1213.	15.03	242.	334.1	530.	15.47	3098.	3340.	3340.	1079.	TF
10000. FT ALTITUDE															
0.4	670.5	105.6	1.262	38.4	1551.	11.49	456.	484.9	537.	14.04	4729.	5185.	12185.	2940.	TF
0.4	670.5	105.6	1.262	38.4	1551.	11.49	455.	484.9	537.	14.04	4729.	5184.	12184.	2940.	TF
0.4	646.5	100.0	1.235	36.4	1493.	11.30	355.	468.2	533.	13.74	4184.	4538.	11288.	2603.	TF
0.4	595.6	90.8	1.180	32.1	1374.	10.95	175.	432.6	525.	13.15	3108.	3283.	9501.	1959.	TF
0.4	525.9	76.8	1.116	26.7	1228.	10.63	19.	383.5	516.	12.44	1841.	1860.	7350.	1287.	TF
0.4	458.2	62.3	1.063	21.2	1118.	10.40	-66.	336.1	508.	11.87	854.	788.	5572.	810.	TF
0.4	446.8	59.9	1.055	20.2	1101.	10.37	-75.	328.2	507.	11.78	711.	636.	5300.	741.	TF
0.4	436.4	57.6	1.048	19.3	1086.	10.35	-83.	321.1	506.	11.70	587.	504.	5061.	681.	TF
0.4	426.6	55.5	1.042	18.3	1074.	10.32	-88.	314.3	505.	11.64	474.	386.	4840.	627.	TF
0.4	417.5	53.5	1.036	17.4	1061.	10.30	-93.	308.1	505.	11.57	374.	281.	4640.	576.	TF
20000. FT ALTITUDE															
0.6	669.4	107.7	1.283	30.4	1497.	8.02	283.	376.2	520.	10.90	2955.	3238.	11088.	2288.	TF
0.6	669.4	107.7	1.283	30.4	1497.	8.02	283.	376.2	520.	10.90	2955.	3238.	11088.	2288.	TF
0.6	662.8	105.9	1.272	29.8	1470.	7.94	245.	372.8	518.	10.81	2828.	3073.	10846.	2172.	TF
0.6	651.9	103.0	1.255	28.8	1432.	7.83	194.	367.2	516.	10.66	2625.	2819.	10465.	2009.	TF
0.6	633.9	98.2	1.226	27.3	1379.	7.68	125.	357.7	512.	10.42	2302.	2427.	9861.	1780.	TF
0.6	616.1	94.3	1.200	25.7	1326.	7.55	63.	348.4	508.	10.20	2002.	2065.	9291.	1564.	TF
0.6	579.9	86.4	1.151	22.7	1219.	7.31	-36.	329.4	501.	9.78	1428.	1392.	8193.	1175.	TF
0.6	525.2	71.7	1.083	18.2	1072.	7.07	-121.	300.5	492.	9.21	669.	548.	6708.	713.	TF
36089. FT ALTITUDE															
0.6	678.5	110.0	1.298	16.4	1351.	3.96	169.	197.9	456.	5.35	1523.	1692.	5555.	1121.	TF
0.6	678.5	110.0	1.298	16.4	1350.	3.96	169.	197.9	456.	5.35	1523.	1692.	5555.	1120.	TF
0.6	667.5	107.2	1.279	15.8	1308.	3.89	136.	195.0	453.	5.28	1417.	1553.	5353.	1026.	TF
0.6	651.1	102.8	1.253	15.0	1258.	3.81	97.	190.6	450.	5.17	1268.	1365.	5072.	914.	TF
0.6	642.7	100.4	1.240	14.7	1237.	3.78	82.	188.2	448.	5.11	1195.	1276.	4935.	867.	TF
0.6	632.8	97.9	1.225	14.2	1213.	3.74	64.	185.5	446.	5.05	1110.	1173.	4776.	812.	TF
0.6	621.2	95.4	1.208	13.7	1183.	3.70	43.	182.4	444.	4.98	1014.	1057.	4594.	748.	TF
0.6	592.9	89.5	1.168	12.4	1111.	3.60	2.	174.7	439.	4.82	792.	794.	4169.	605.	TF
0.6	522.6	71.2	1.080	9.5	952.	3.44	-57.	155.4	429.	4.46	312.	255.	3231.	333.	TF

TABLE XXVI. PD370-30 PERFORMANCE (MCDONNELL INSTALLATION)
(Vertical flight, sea level static, intermediate power, 3 engines, 3 fans)

PITCH DEG	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
					LEVEL FLIGHT		549.5 R	DAY	DRY						
0.2	668.6	100.6	1.215	45.0	1689.	16.11	955.	597.8	585.	17.47	10154.	11109.	11109.	3679.	TF
0.0	43.8	100.6	0.0	42.4	1688.	15.19	542.	0.0	0.	0.0	0.	542.	542.	3519.	TS
0.8	676.4	100.6	1.215	0.C	0.	0.0	0.	649.3	585.	17.44	11106.	11106.	11106.	0.	LF
					ROLL CONTROL		549.5 R	DAY	DRY						
7.3	726.1	100.6	1.259	45.1	1689.	16.12	958.	651.4	593.	18.04	12112.	13070.	13070.	3670.	TFH
-6.9	585.6	100.6	1.165	44.6	1691.	16.08	937.	517.2	577.	16.74	7599.	8536.	8536.	3655.	TFL
0.0	43.8	103.7	0.0	42.4	1687.	15.19	539.	0.0	0.	0.0	0.	539.	539.	3516.	TS
-0.2	667.2	100.6	1.210	0.C	0.	0.0	0.	640.5	584.	17.36	10803.	10803.	10803.	0.	LF

TABLE XXVII. PD370-30 PERFORMANCE (MCDONNELL INSTALLATION)

(Vertical flight, sea level static, intermediate power, 2 engines, 3 fans) (turbofan out)

PITCH DEG	WCOR LB/SEC	NCOR %	FPR	WP LB/SEC	TTP R	PTP PSI	FNP LB	WS LB/SEC	TTS R	PTS PSI	FNS LB	FNT LB	FGT LB	WF LB/HR	
					LEVEL FLIGHT		549.5 R	DAY	DRY						
-8.5	567.0	100.6	1.150	44.7	1690.	16.09	944.	502.0	575.	16.61	7148.	8091.	8091.	3671.	TF
0.0	43.8	100.6	0.0	42.4	1687.	15.19	542.	0.0	0.	0.0	0.	542.	542.	3518.	TS
-7.7	576.5	100.6	1.155	0.0	0.	0.0	0.	554.9	577.	16.66	8097.	8097.	8097.	0.	LF
-8.2	558.0	100.6	1.169	0.0	0.	0.0	0.	533.8	578.	16.88	8091.	8091.	8091.	0.	EOF
					ROLL CONTROL		549.5 R	DAY	DRY						
-0.9	656.5	100.6	1.207	44.9	1689.	16.11	952.	586.5	583.	17.36	9774.	10726.	10726.	3671.	TF
0.0	43.8	100.6	0.0	42.4	1688.	15.19	542.	0.0	0.	0.0	0.	542.	542.	3518.	TS
-8.0	572.7	100.6	1.153	0.0	0.	0.0	0.	551.3	576.	16.64	7993.	7993.	7993.	0.	LF
-16.9	451.8	100.6	1.114	0.0	0.	0.0	0.	430.6	570.	16.09	5261.	5261.	5261.	0.	EOF
					LEVEL FLIGHT		549.5 R	DAY	WET						
-6.3	596.2	100.6	1.163	50.8	1665.	16.48	1192.	523.7	577.	16.78	7778.	8970.	8970.	4279.	TF
0.0	44.8	106.8	0.0	45.1	1673.	15.25	604.	0.0	0.	0.0	0.	604.	604.	3834.	TS
-5.3	607.0	100.6	1.172	0.0	0.	0.0	0.	583.9	579.	16.88	8967.	8967.	8967.	0.	LF
-5.8	588.0	100.6	1.187	0.0	0.	0.0	0.	561.8	581.	17.12	8963.	8963.	8963.	0.	EOF
					ROLL CONTROL		549.5 R	DAY	WET						
3.8	704.1	100.6	1.237	51.7	1663.	16.54	1234.	624.3	588.	17.74	11100.	12334.	12334.	4341.	TF
0.0	44.8	106.8	0.0	45.1	1673.	15.25	605.	0.0	0.	0.0	0.	605.	605.	3833.	TS
-5.9	600.4	100.6	1.168	0.0	0.	0.0	0.	577.6	578.	16.84	8777.	8777.	8777.	0.	LF
-16.9	451.2	100.6	1.115	0.0	0.	0.0	0.	428.7	570.	16.08	5221.	5221.	5221.	0.	EOF

LIFT FAN ASSEMBLY

Hamilton Standard conducted a preliminary design of a variable-pitch lift fan for the RTA.

The major systems of the lift fan were defined and analyzed to provide adequate structural integrity for the RTA mission. The system weights and key elements of the fan were defined; the following key elements were identified:

- Rotor
  - Blade
  - Disk
  - Retention
  - Actuator
  - Spinner
- Gear Reduction Assembly
  - Gears
  - Bearings
  - Lubrication system
- Fan Case
  - Structure
  - Vane oil cooler
- Pitch Control System
  - Beta regulator

Preliminary layout and installation drawings for the lift fan, lift/cruise fan, and major systems were prepared (Figures 28 through 30). The lift/cruise fan is a direct application of the lift fan rotor and pitch control system.

The component designs were based on the mechanical and aerodynamic loads encountered in meeting the requirements of the RTA. The structural design was sized by the particular "worst-case" loading determined through an analysis of the RTA operating conditions. As part of this analysis, a primary structural requirement of the blade design was to withstand an FOD 2.2-lb bird strike.

The design analysis in this report includes a discussion and summary of the critical design parameters and calculations to provide a basis for understanding the design criteria and techniques employed in selecting and sizing the key system components. The lift fan mechanical design is representative of present-day technology, providing a mechanical design that will ensure successful operation in the RTA.

ROTOR SYSTEM

The rotor system is common to both the lift and lift/cruise fans. It consists of the blades, disk, variable-pitch actuator, and spinner (Figure 31). This assembly provides for rotating, attaching, and changing pitch of the rotor blades.

The rotor design is based on previous Hamilton Standard variable-pitch fan and propeller designs. The rotor is designed to aerodynamic as well as structural requirements. A workable combination of smooth, efficient aerodynamic contours and sound structural members is used to provide peak performance and structural integrity.

The rotor system is designed to vary the blade pitch angle, upon command, to vary the thrust output of the fan. Blade pitch can be varied from +10 to -40 degrees with respect to the design-point blade angle. Blade pitch is changed by attaching the blade to the rotor disk by a bearing. The blade is then controlled by an attached linkage and hydraulic actuator.

The actuator is mounted in the center of the assembly and rotates with the disk. The actuator is powered by aircraft hydraulics and has two independent hydraulic drive chambers to ensure blade pitch control in the event of a fan control system failure. The hydraulic fluid to the actuator chambers is transferred from the stationary control system through a "transfer bearing." Control of the pitch change actuator is provided by the control system described under the subsequent "Pitch Control System" heading.

The V/STOL fan blade is of a spar-shell design consisting of boron/aluminum shells and a titanium spar to minimize blade and rotor weight. The composite blade accounts for an across-the-board lightweight rotor design.

Blade

At the conclusion of Hamilton Standard's work under NASA contract NAS3-20033, it was noted that the 26-bladed V/STOL fan of that study had two blade natural vibratory frequencies (critical speeds) in the fan operating speed range as well as a torsional flutter parameter which needed to be increased. It was judged that the modifications necessary to adjust these factors could be achieved by minor modifications of the design—i.e., local blade thickness changes and [illegible] ply orientation changes of the blade composite shells. Subsequent analyses showed, however, that modifications within the constraints of a 26-blade fan did not provide sufficient improvement. The blade preliminary design resulted in a reduction in the number of blades to 22. Also, minor changes were made to the blade chord, thickness ratio, hub/tip ratio, and sheath material.

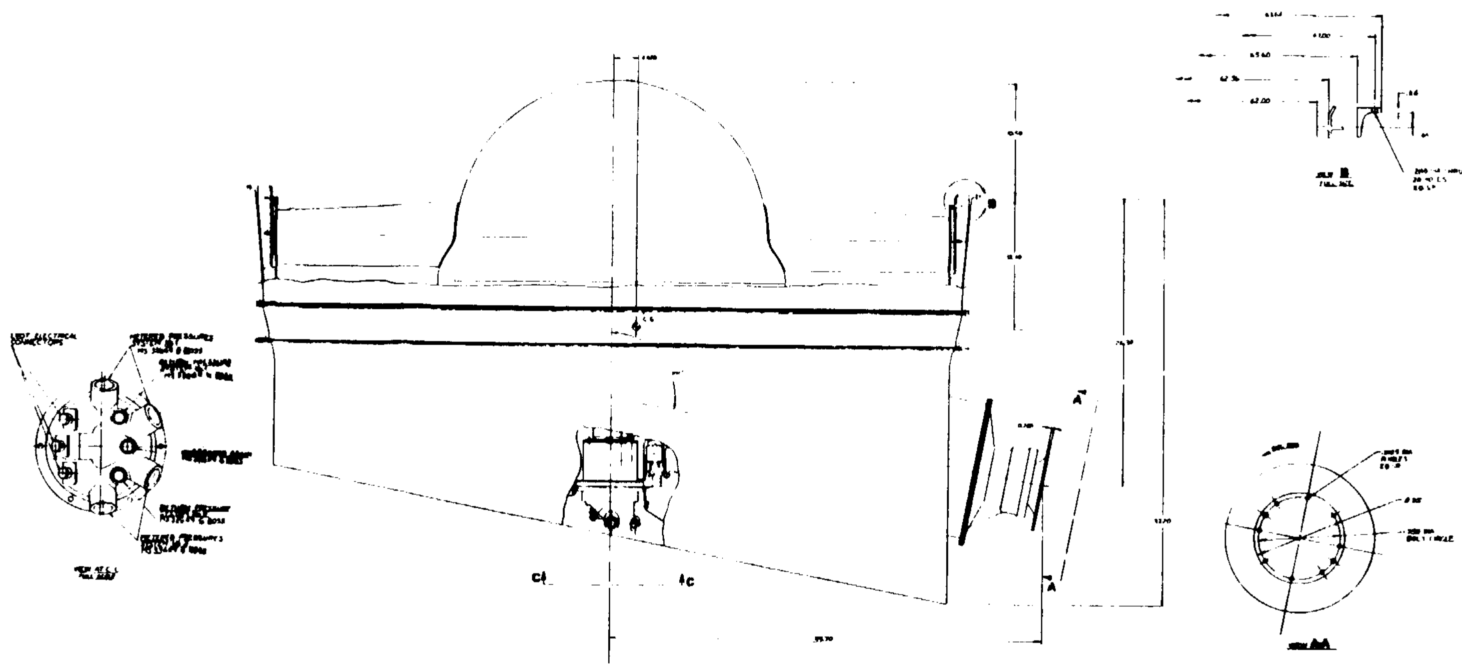


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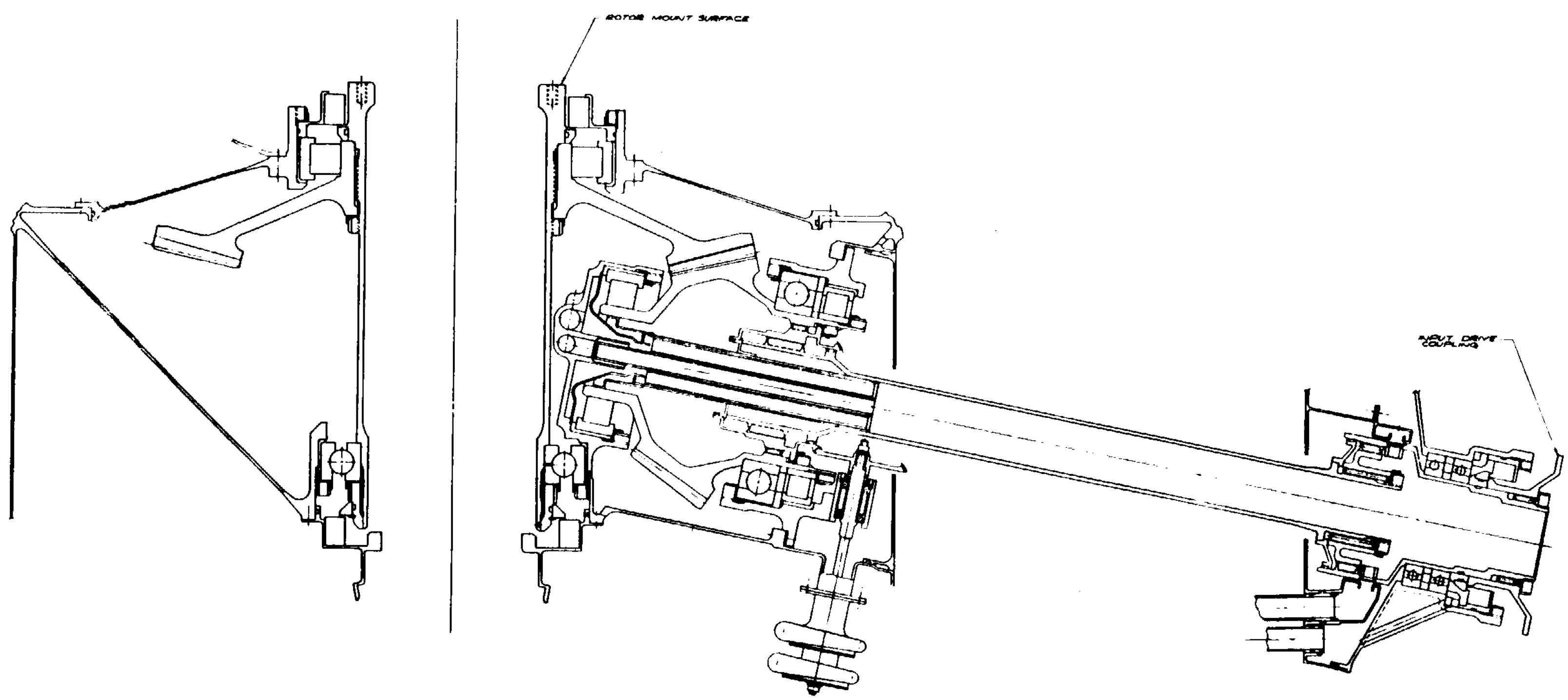
Figure 28. Lift fan installation.



95-A

Figure 45. Rotor mount and drive assembly.

B

TABLE XXXIV. SPLINE SUMMARY						
Location	Number of teeth	Pitch	Pressure angle (deg)	Contact stress (psi)	Shear stress (psi)	Application
Input flange	24	8/12	25	14,825	21,435	Clamped by nut
Small diameter adapter spline	30	12/17	25	12,340	17,450	Clamped by nut
Large diameter adapter spline	44	10/14	20	4,920	8,465	Quillshaft angular misalignment required
Tailshaft	72	10/20	30	7,870	7,665	Subject to bending moment
Bevel pinion	35	8	25	4,515	9,775	Quillshaft angular misalignment required

Bearing loads are as follows:

Pinion—6400 hp at 8543 rpm (47,837 in.-lb mean effective torque)
Thrust load = +7665 lb
Separating component = +3356 lb
Tangential tooth load = 12,050 lb

Gear—6400 hp at 3543 rpm (113,847 in.-lb mean effective torque)
Thrust load = +4757 lb
Separating component = +6884 lb
Tangential tooth load = 12,050 lb

Rotor Support—Thrust = +5230 lb
Moment = 43,846 in.-lb
Side load = 1232 lb (acting 90° to UHS of rotation)

Figure 46 depicts the resulting thrust and separating component loads for pinion and gear. Determination of web location and the resultant tooth forces are graphically shown.

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Several bearing arrangements were analyzed for the input pinion and tailshaft to determine optimum bearing proportions and bearing locations. These bearing concepts include those shown in Figures 47 through 51.

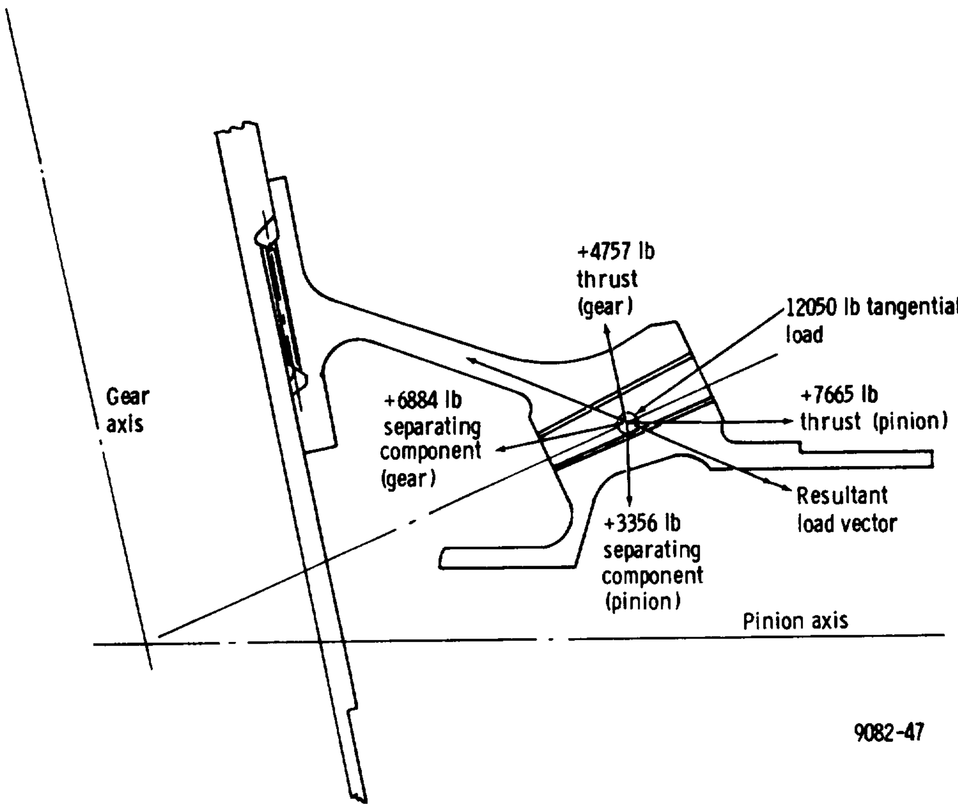

Figure 46. Bevel gear load analysis at 6400-hp condition.

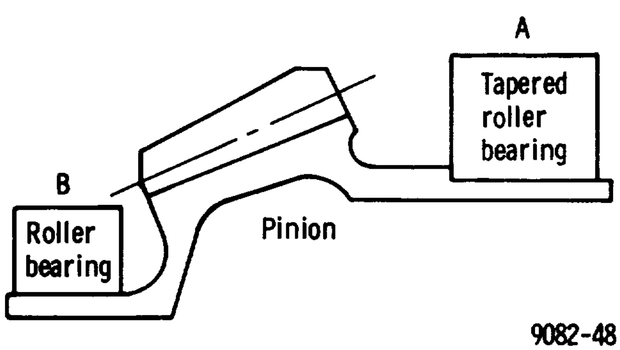

Figure 47. Pinion bearing arrangement I.

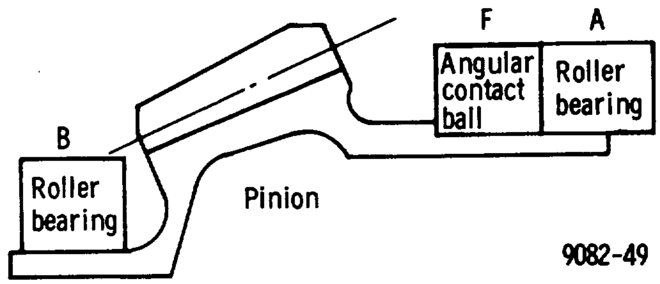

Figure 48. Pinion bearing arrangement II.

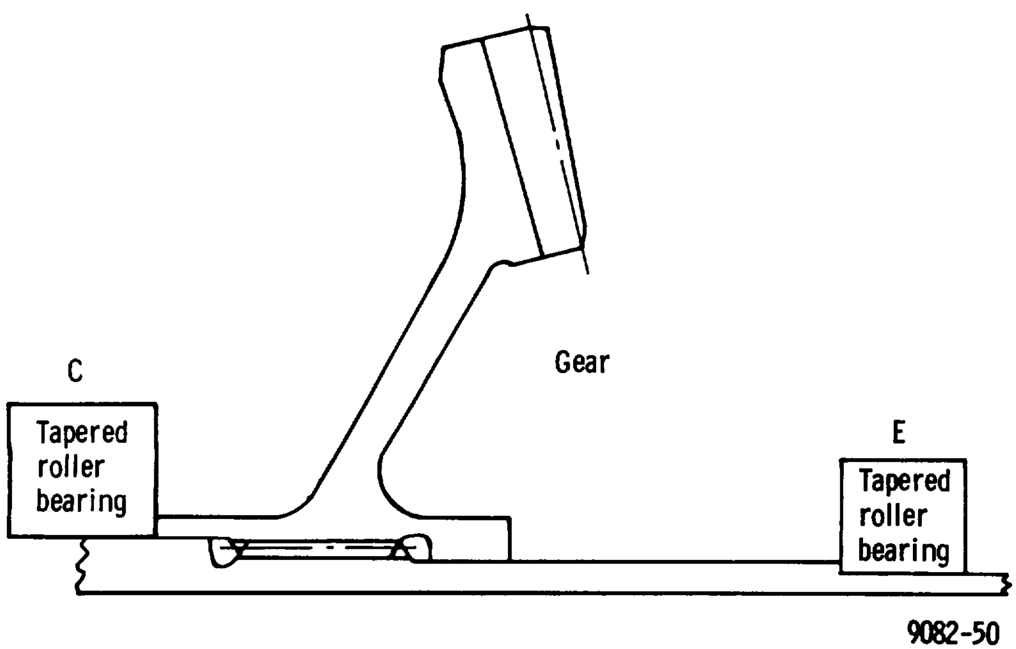

Figure 49. Gear bearing arrangement I.

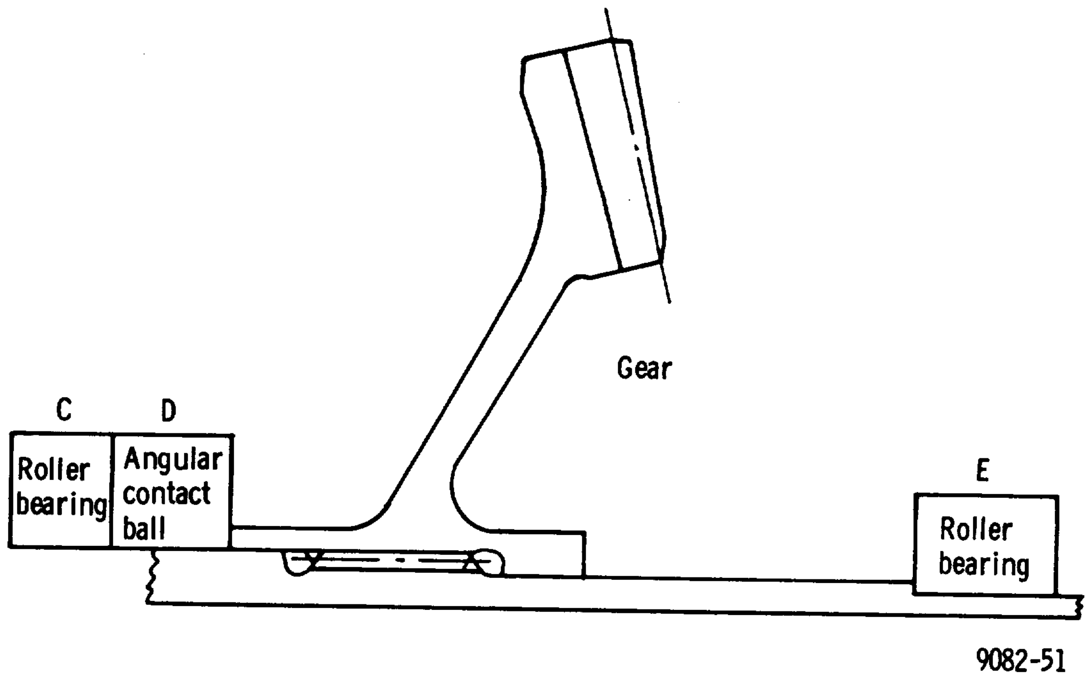

Figure 50. Gear bearing arrangement II.

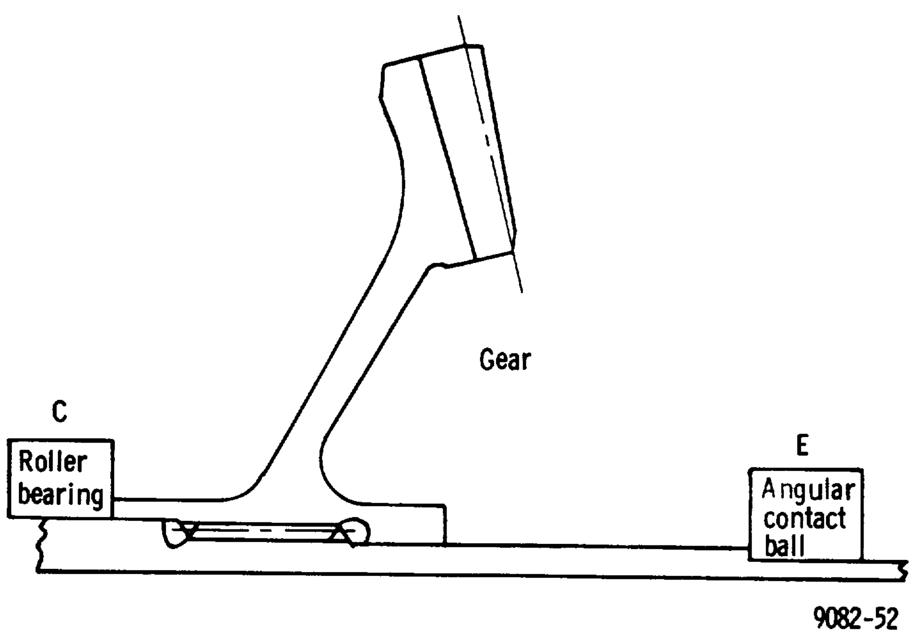

Figure 51. Gear bearing arrangement III.

In assessing the various bearing concepts, the assumption was made that angular contact ball bearings, when used adjacent to a roller bearing, are relieved on the bearing OD to eliminate a potential tolerance condition wherein the ball bearing could absorb all the radial loads. The relieved bearing will then react thrust loads only.

Because a reliability requirement was not specified, a design life goal was established for the bearings which would provide an overall lift fan MTBF of approximately 50,000 aircraft flight hours. With this total lift fan MTBF goal, it is necessary to have the bearing MTBF for five bearings in the order of 80,000 aircraft hours. This requires a bearing actual calculated B_{10} life of 2500 hours for the 117 hours of actual RTA lift fan operating hours with a Weibull bearing failure rate slope of 1.5.

Although tapered roller bearings provide a lighter assembly weight, it was felt that the high rim speeds associated with the use of tapered roller bearings on the pinion gear would unnecessarily increase the development costs for the RTA aircraft. Therefore, the bearing configuration depicted by Figure 48 was selected for the pinion mounting.

An objective of the gearbox design was to provide a short fan/gearbox assembly, which made it desirable to have a short-axial-length bearing between the bevel gear and the rotor (bearing C of Figure 51). The arrangement of Figure 51 was therefore selected for the tailshaft bearings.

A description of the selected bearing configurations is given in Table XXXV.

TABLE XXXV. BEARING ANALYSIS SUMMARY

Figure	Bearing	Type	Dynamic life (hr)	DN	Weight (including races) (lb)
48	A	Roller	2500	1.20×10^6	6.01
48	F	Ball	2500	1.20×10^6	8.63
48	B	Roller	2500	5.98×10^5	6.80
51	C	Roller	2500	7.09×10^5	17.26
51	E	Ball	2500	6.02×10^5	10.01

Lubrication System

The gear reduction utilizes a pressure-fed lubrication system with integral pumps, reservoir, and cooling system. The system is designed to the values in Table XXXVI.

TABLE XXXVI. LUBRICATION SYSTEM DESIGN POINT	
Nominal fan power, hp	6400
Maximum transient fan power, hp	8600
Lubricating oil	MIL-L-7808 or MIL-L-23699
Oil temperature, °F	275 max
Oil flow rate, gal/min	12

A lubrication schematic indentifying the oil distribution throughout the gearbox is shown in Figure 52. Oil from a centrifugal pressure pump is circulated through the fan case vane and is then distributed to the lubrication points. All bearings are directly lubricated and cooled by pressurized jets which direct oil to the inner race. A spray bar directs pressurized oil to the bevel gear teeth. Splines, operating with relative motion between mating parts, are flooded with oil to eliminate wear and fretting corrosion. Oil circulating through these splines is allowed to excape to the open sump. Hot oil gravitates to the bottom of the gearbox where it is delivered to a scavenge pump and injected into an air-oil separator within the input drive shaft. Separated oil is then returned to the oil reservoir.

Incorporation of the air-oil separator reduces the required reservoir storage capacity and quantity of oil by two gallons. Conventional lubrication systems without an air-oil separator normally require a 15-second dwell time for air separation. The estimated weight saving for tank size reduction and associated oil requirements is 14 lb. An oil filter with a bypass valve and "ΔP indicator" is contained within the gearbox. The bypass valve allows oil to bypass a clogged filter. The ΔP indicator gives visual evidence of a dirty filter and is actuated when the pressure differential is lower than the actuation point of the bypass valve.

The gearbox is cooled by circulating oil through the fan vanes. Heat rejection requirements were based on estimated gear and bearing losses at a steady-state power of 6400 hp with transients at 8600 hp. The 0.75% loss is based on experience with several Hamilton Standard bevel gearbox designs and results in a loss of 48 shp. An additional pumping loss of 4 shp brings the total to 52 shp.

To determine the requirements for the cooler oil, the cooling inherent in the design without a cooler was estimated. A substantial amount of cooling (22% of the nominal cooling requirement) was calculated from the hot oil film that would be gravity fed to the sump along the gearbox wall separating the gearbox from the primary airflow path. Other inherent cooling from convection was calculated to provide 4% of the nominal cooling needs. The oil heat exchanger thus must provide for 74% of the nominal heat load.

The fan stator vanes were chosen as a surface that could be utilized for a heat exchanger because the vanes provide a relatively large surface area exposed to primary airflow. This approach eliminates the need of an external oil cooler.

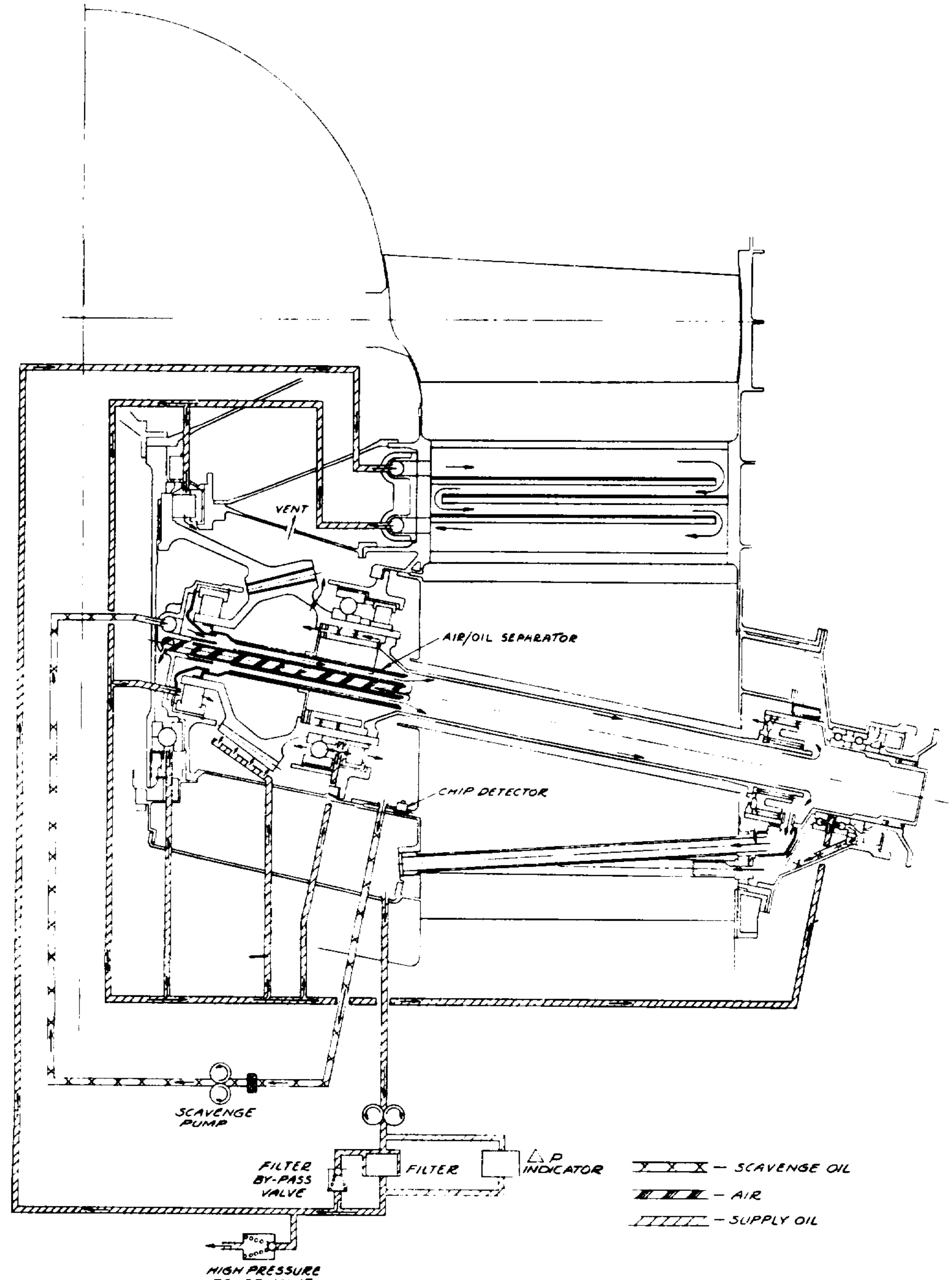

Figure 52. Lift fan lube schematic.

An internal baffle (fin) design was selected for the vanes. This provides good cooling at a low weight, pressure drop, and cost. Figure 53 is a sketch of the design. The oil flow path is through successive vanes connected in series by headers at the vane endwalls. The optimum number of baffles, their orientation, and the selection of series versus parallel flow, or a combination of each, was determined by parametric analysis.

To determine the effect of temporary increases in fan load on the heat exchanger design, an analysis was performed to determine the variation of oil temperature with time at several fan power levels. As a result, one vane was added to the heat exchanger design to handle the anticipated transient power requirement. The final cooler consists of 10 cooling vanes and is designed for an oil flow rate of 12 gal/min. It will provide a cooling rate of 1682 Btu min for oil entering the cooler at 275°F and with fan through-flow air at 100°F. This cooling, in addition to other cooling inherent in the fan unit, can reject to the fan airstream a steady-state heat load equivalent of 52 hp. The variation in oil temperature with time is shown in Figure 54 for several fan power levels and initial oil temperature. Figure 54 indicates that the heat exchanger will maintain safe oil operating temperature for up to 1.0 minute of transient operation at a fan power level of 8600 hp. It is felt that this transient capacity will be sufficient to meet the needs of the RTA.

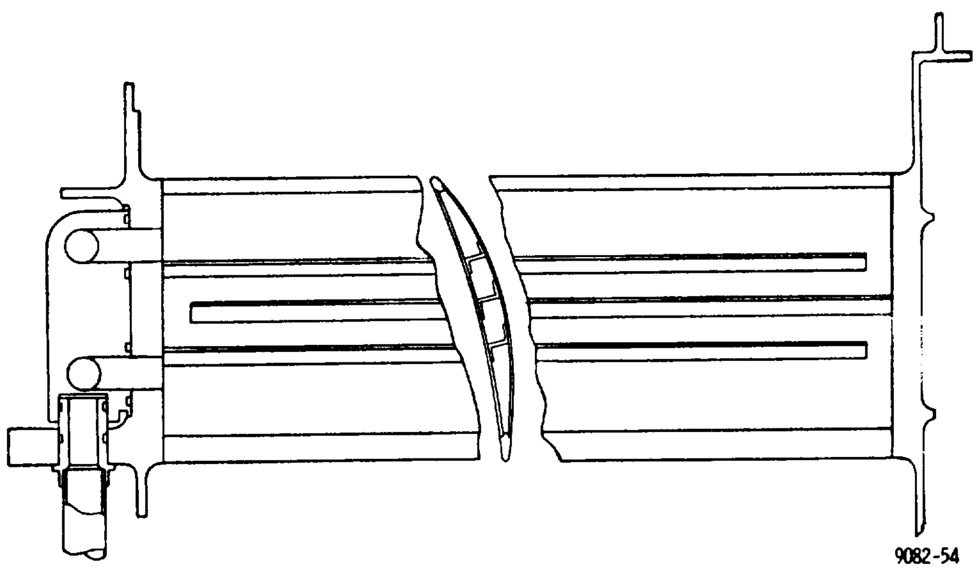

Figure 53. V/STOL vane oil cooler.

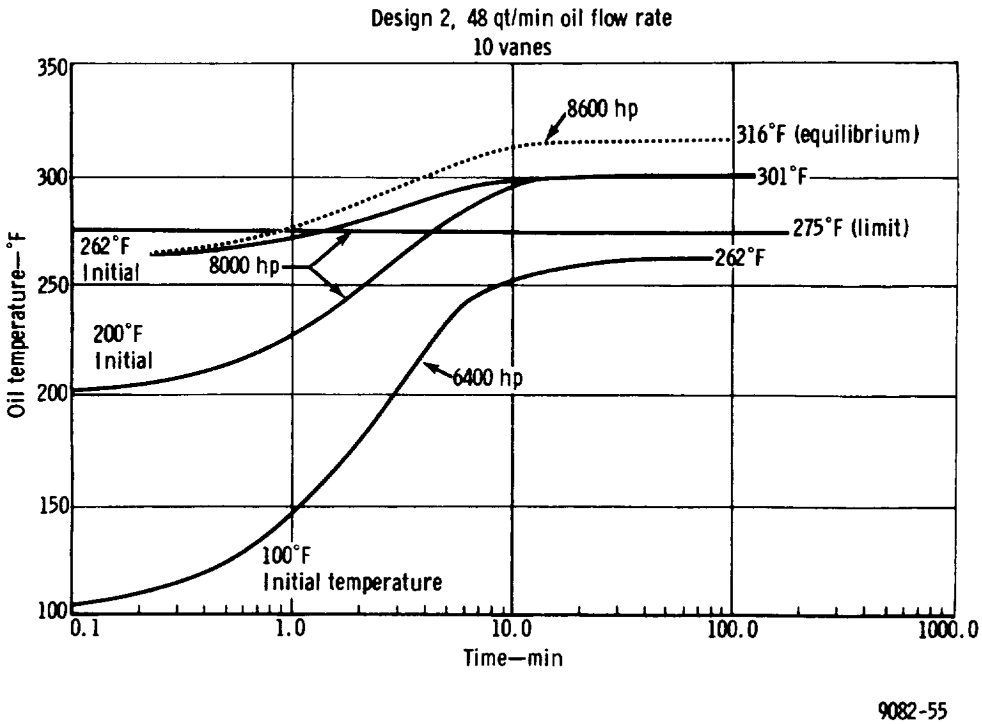

Figure 54. Lift fan oil cooler transient response.

FAN CASE

The fan case consists of an inner ring, the fan exit guide vanes, an outer ring, and the fan wrap and rub strip. Its function is to maintain the fan duct flow path, to transmit the fan structural loads to the airframe, and to provide gearbox cooling as described previously. The fan case assembly is shown in Figure 55. It is a titanium weldment fabricated from fully machined forgings and sheet metal.

Preliminary analyses of the fan case indicated that it is sized by stiffness considerations rather than stress limitations. For example, the unbalance loads associated with the loss of a blade shell are one of the larger loads imposed on the fan case, yet result in only ±1300 psi stress in the vanes. The following four vibration modes, as illustrated in Figure 56, were studied:

- Vertical (along thrust axis)
- Shear (perpendicular to thrust axis)
- Torsional (about center line of rotation)
- Moment (pitch or roll)

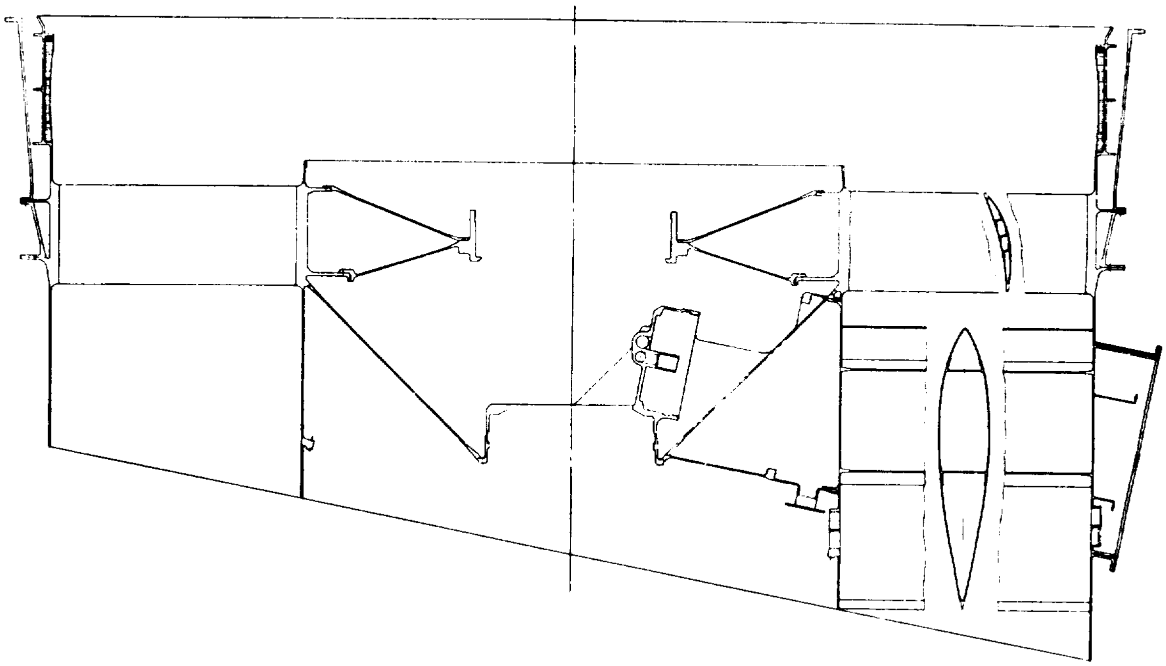

Figure 55. Lift fan case assembly.

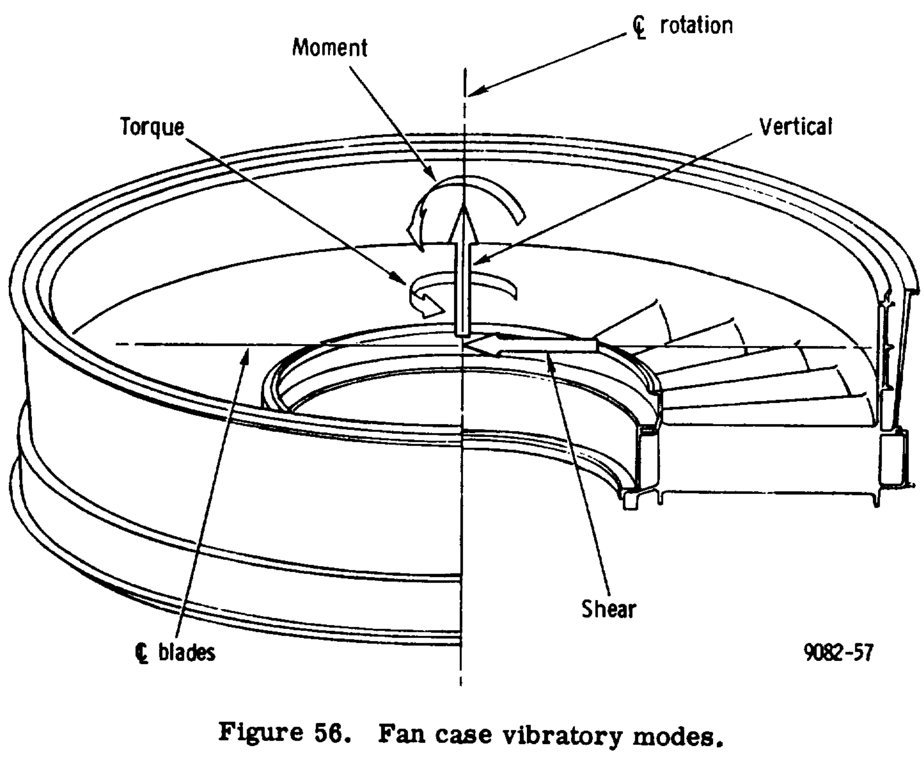

Figure 56. Fan case vibratory modes.

In the vertical mode, the vanes act as cantilevers connected to the fan case inner ring, which functions as a torus in reacting the vane moment loads (Figure 57). The fan case outer ring is relatively flexible and does not have a significant effect on the vertical frequency. Deflections of the thrust bearing support cone were determined by a shell of revolution computer program. The overall spring rate, K_{eff}, in the vertical mode is:

$$K_{eff} = \frac{1}{\frac{1}{K_v} + \frac{1}{K_r} + \frac{1}{K_c}}$$

where

K_v = vane spring rate

K_r = inner ring spring rate

K_c = thrust cone spring rate

The natural frequency, W_R, is:

$$W_R = (1/2\pi)\sqrt{(K_{eff}/M)}$$

where M is the mass of the weight supported by the fan case.

In the shear or lateral direction, the fan is supported by the fan case inner ring, the vanes, the outer ring, and the mount ring (see Figure 58). Those vanes that act as columns provide high lateral stiffness whereas those acting as beams add little to the overall fan case lateral stiffness. Therefore, the applied load and its reaction is assumed to act over 90-degree segments

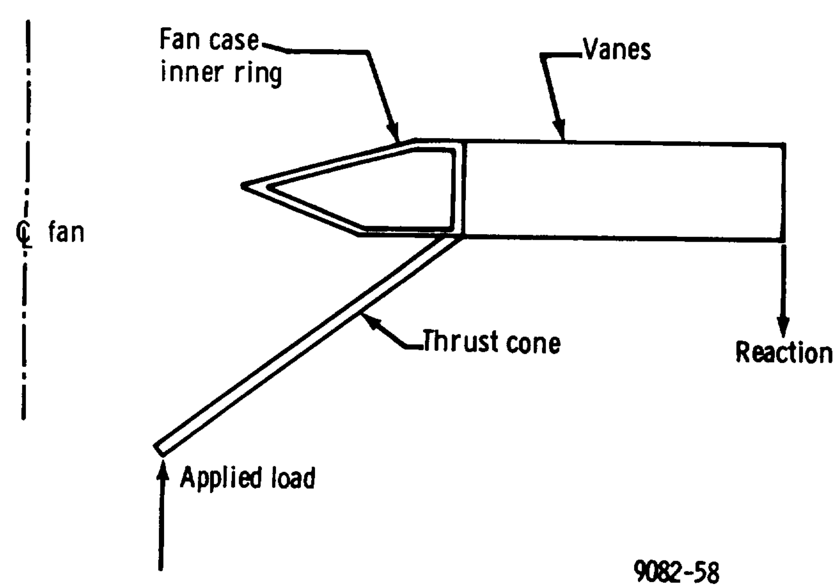

Figure 57. Fan case vertical loading.

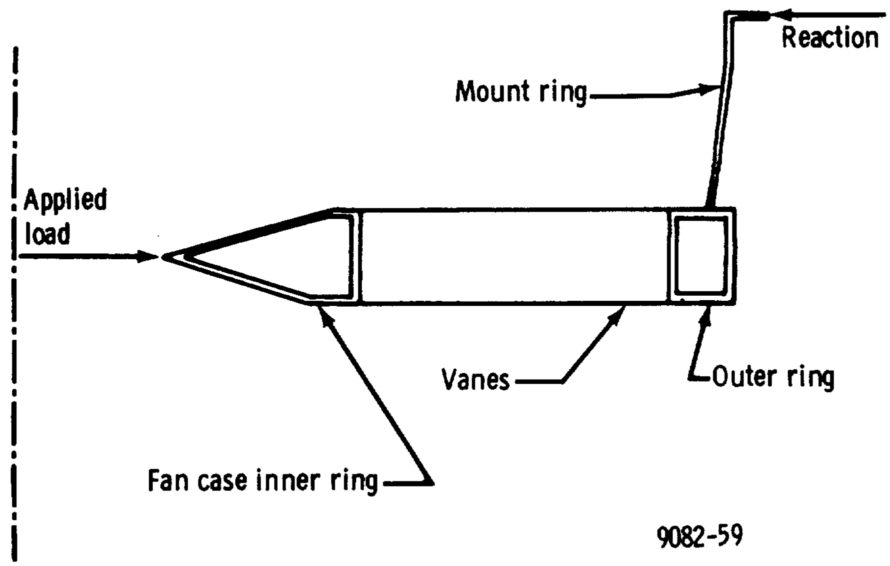

Figure 58. Fan case shear loading.

of the fan case where the vanes are in tension and compression. The outer ring redistributes the load from the two 90-degree arcs to a shear load on the mount ring. The mount ring is analyzed as a cantilever beam. The spring rates of the elements of the fan case are added in series to obtain an effective spring rate. Frequency is calculated as described previously.

As shown in Figure 59, torsion is reacted by a shear load at the outer diameter of the vanes. The vanes are assumed to be cantilevered from the fan case inner ring and a torsional stiffness is determined. Frequency is determined by:

$$W_R = (1/2\pi)\sqrt{(K_T/I_M)}$$

where K_T is the torsional stiffness of the system and I_M is mass moment of inertia of the non-rotational elements of the fan assembly.

Out-of-plane rotor moments are reacted by a shear load at the outer diameter of the vanes. This shear load has a sine distribution around the vane assembly. The vanes act as cantilevers from the fan case inner ring. In addition, rotor moments produce shear and bending deflections in the thrust cone.

Results of the mount frequency analysis are as follows:

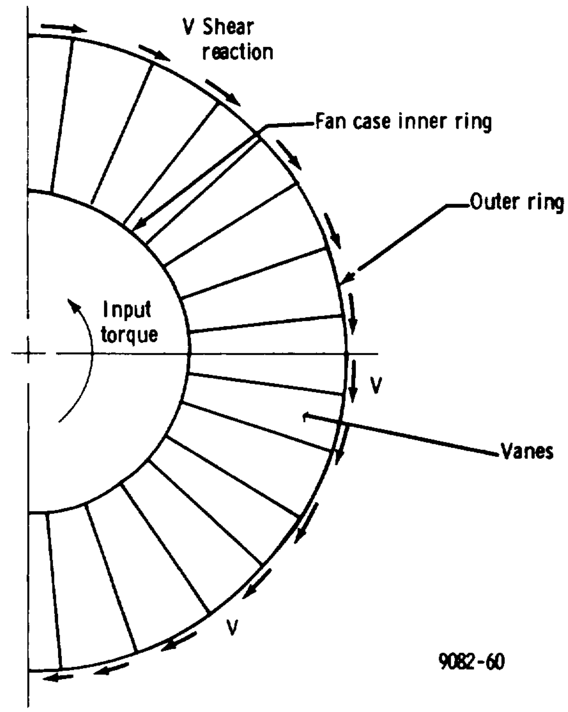

Figure 59. Fan case reaction loads.

Mode	Natural Frequency
Vertical	65 Hz
Shear	179 Hz
Torsional	65 Hz
Moment	98 Hz

These frequencies are shown graphically in Figure 60. It can be seen that all fan case natural frequencies are separated from the primary fan excitation, 1P, by at least a 10% margin. While crossovers of the higher orders (2P, 3P, 4P) occur within the operating range, these orders are reactionless modes and, as such, have no appreciable excitations.

A preliminary assessment of the whirl flutter characteristics was also made. Isolation of whirl flutter depends on the stiffness and inertia properties of the fan support structure and the nacelle attachment structure. The V/STOL lift fan aerodynamic, inertial, and geometric characteristics were compared with other similar Hamilton Standard propulsor designs to determine a minimum

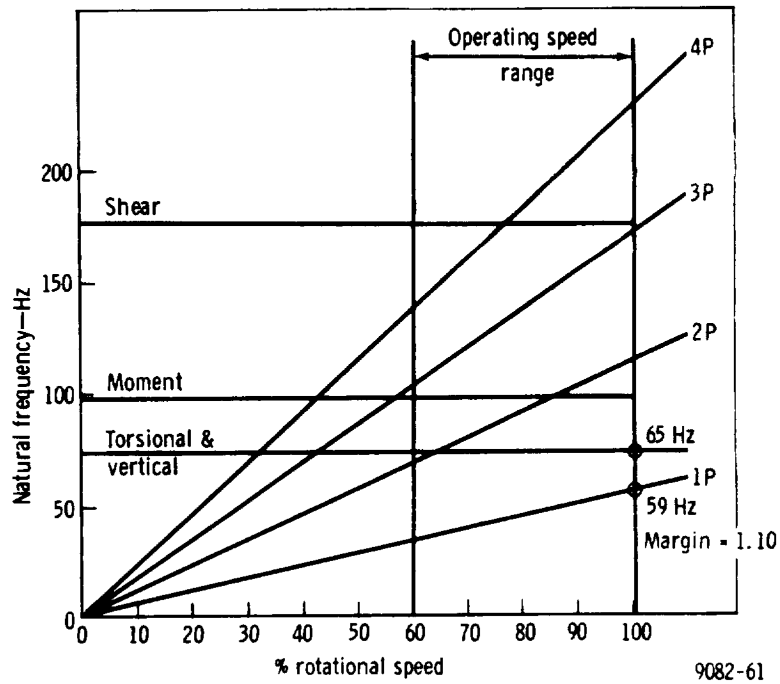

Figure 60. Fan case natural frequencies.

mount stiffness requirement for the V/STOL Fan. The calculated lift fan mount stiffness, 116.6×10^6 in.-lb/rad, is well in excess of the 30×10^6 in.-lb/rad required to prevent whirl flutter.

An analytical appraisal of fan blade containment requirements led to the conclusion that the fan case as presently designed will contain the blade exclusive of the spar. Additional material (approximately 80 lb) in the fan case would be required to contain a complete blade including the spar.

Fluctuating pressure in the duct was estimated to evaluate potential acoustic fatigue damage. Measurements made during Hamilton Standard's 4.6-ft diameter variable-pitch fan program were used as the basis for the estimate. The maximum pressure fluctuation levels occurred in the plane of rotation and were estimated to be ± 1.12 psi (169 dB) at the blade passage frequency of 1300 Hz. Duct stresses associated with this pressure were calculated to be negligible.

PITCH CONTROL SYSTEM

The pitch control system positions the variable-pitch rotor blades at any selected station within an allowable operating range. The system consists of a hydraulic actuator, a hydraulic transfer bearing, control modules, and associated hydraulic and mechanical power transfer lines. The hydraulic power is from the aircraft systems.

The pitch control system draws heavily on proved concepts used in current aircraft applications. The concept was selected to provide the light weight, high reliability, and safety necessary for a primary flight control. It provides both hydraulic and mechanical redundancy to allow continued operation in the event of a hydraulic failure within or outside the fan system or the failure of selected structural components.

The control system is illustrated schematically in Figure 61.

The pitch change actuator employs a dual linear hydraulic actuator that incorporates both hydraulic and structural redundancy. The actuator, as shown in Figure 62, is supported by the disk and connected to the blades by mechanical links. It also incorporates a splined torque restraint which reacts the tangential loads from the blade links. To separate possible actuator hydraulic fluid seepage from the gearbox lubricating oil, the torque restraint and an additional sleeve around the transfer bearing are provided. These sleeves collect any hydraulic fluid seepage, which is then ported through the gearbox to an overboard drain.

The pitch change actuator is controlled by two valve modules (Beta regulators), mounted remotely from the actuator in an area of the nacelle that is readily accessible for servicing. The Beta regulator is described in detail under the subsequent "Beta Regulator" subheading. Metered pressure from the Beta regulator is fed to the actuator via drilled lines, tubes, and the transfer bearing.

Actuator position is fed back to the propulsion computer, which compares this position with the desired position and then provides any necessary correction commands to the Beta regulators. The actuator position is fed back by three linear variable differential transformers (LVDT's)— one for each of the two redundant hydraulic systems and one for a computer model system which establishes optimum system parameters for current aircraft operating conditions.

The computer also compares the actuator position feedback signals, Beta regulating valve spool position signals, and differential pressure signals from each hydraulic system with each other and with the computer model system to ensure that all systems are functioning properly. Any signal that exceeds predetermined error limits will cause the computer to shut off the affected system and turn on a cockpit warning light.

Pitch change system characteristics for the design are listed in Table XXXVII.

TABLE XXXVII. PITCH CHANGE SYSTEM CHARACTERISTICS	
Number of blades	22
Speed, rpm	3543
Time constant, sec	0.03
Pitch change rate, deg/sec	100
Blade angle range (from design point), deg	-40 to +10
Max flow rate, gal/min	11.5
Fluid	MIL-H-6083
Temperature range, °F	-65 to 275
Supply pressure, psi	3000

The pitch change range was selected to provide for blade movement from the maximum control blade angle to an angle which provides low thrust during start-up. The time constant of 0.03 sec for normal operation was selected for accurate blade angle positioning and immediate response as well as to meet the transient thrust requirements of the aircraft during hover.

The pitch change system loads are determined for conditions that produce either maximum steady stress or maximum cyclic stress. Because an operating spectrum for the fan was not available, a cyclic life requirement was assumed for each load condition. The actuator loads are the loads developed at the blade as a result of centrifugal force, which causes retention friction and a twisting moment on the blade, and an erodynamic twisting moment as the result of air loads. Table XXXVIII lists the summation of these loads for each operating condition.

TABLE XXXVIII. ACTUATOR LOADS

Condition	Cycles	Loads
Maximum normal	2×10^4	-930 ± 930 in. -lb/blade
Hover	1×10^8	-1600 ± 200 in. -lb/blade
Bird strike	1	2750 ± 11,250 in. -lb/blade
Bird strike (summation of blade loads)	1	14,000 in. -lb
Proof pressure	1	4500 psi
Burst pressure	1	7500 psi

All loads occur at 3543 rpm, with the positive loads toward increase pitch and the negative loads toward decrease pitch.

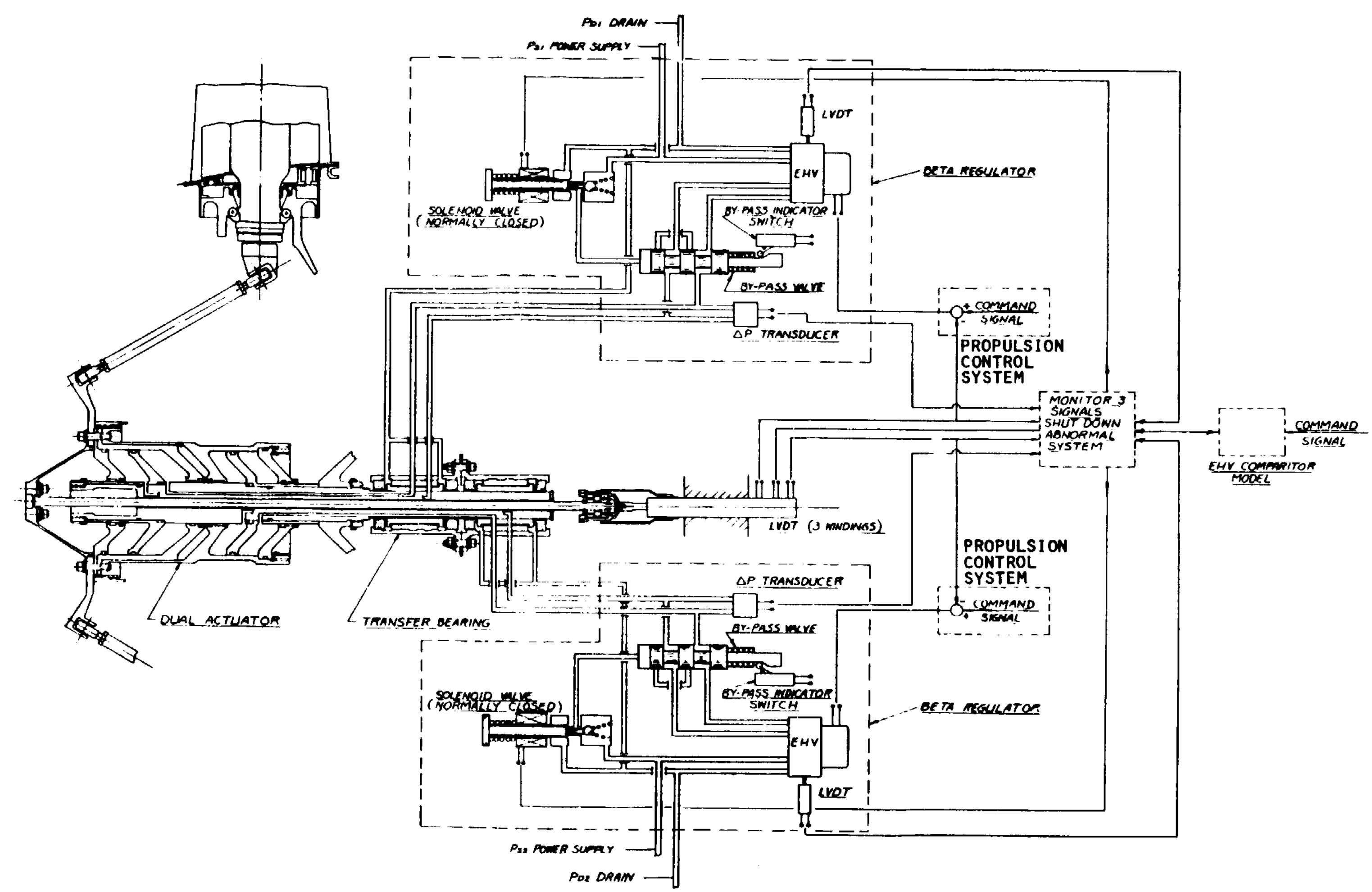

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Figure 61. Pitch change schematic.

B

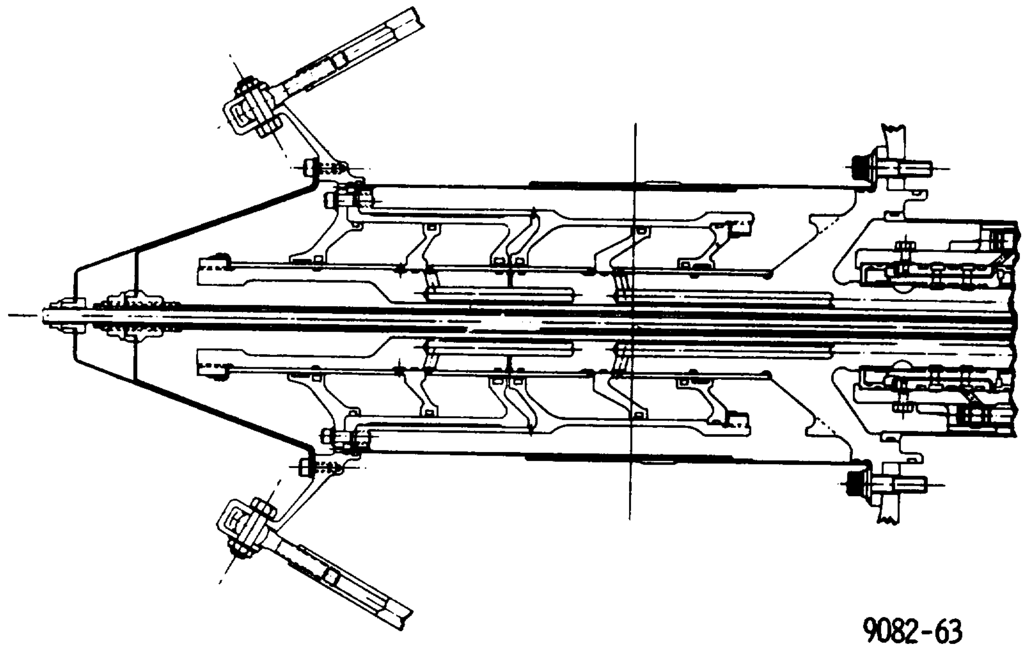

Figure 62. Pitch change actuator.

The actuator elements that were analyzed included the blade link, link pin, link support, torque restraint, piston, and actuator center support. A summary of the stress analysis results for these elements is presented in Table XXXIX.

TABLE XXXIX. SUMMARY OF PITCH CHANGE STRESS ANALYSIS

Element	Maximum stress condition	Maximum stress (psi)
Blade link	Bird strike	48,523
Link pin	Bird strike	84,986
Link support	Burst pressure	86,435
Torque restraint	Max normal load	10,868
Piston	Burst pressure	114,535
Actuator center support	Bird strike	59,581

Stresses are below design allowables.

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Single Acting Actuator Study

A study was made to investigate the feasibility of a single-acting actuator. If the blade twisting moments are always in the decrease pitch direction, the actuator could be designed without a decrease pitch hydraulic chamber for a potential reduction in actuator weight. The blade total twisting moments were investigated for the operating envelope in the cruise and takeoff modes to determine the direction of the moments. The investigation disclosed that the summation of twisting moments on the blades produced net moment reversals for portions of each of these modes and that, therefore, a double-acting actuator is required.

Redundant Actuator Rod Study

In another study, the feasibility of a redundant center rod and its impact on weight and envelope were investigated. Figure 63 is a schematic representation of a means to provide redundant structural load paths in the actuator. The diameter of the inner center support is increased so that oil transfer tubes can be incorporated to prevent a crack from causing oil loss or a structural loss. The outer center support and actuator is then built around the inner center support. An increase in the actuator envelope of approximately 0.6 in. in diameter and 1.0 in. in length is required to accomplish the redundant concept. The resulting weight increase would be approximately 18 lb. Because the maximum normal operating stress in the center rod is 4000 ± 4000 psi with a margin of safety of approximately 16, the probability of failure is very remote; therefore, the base-line concept does not incorporate the redundant center rod.

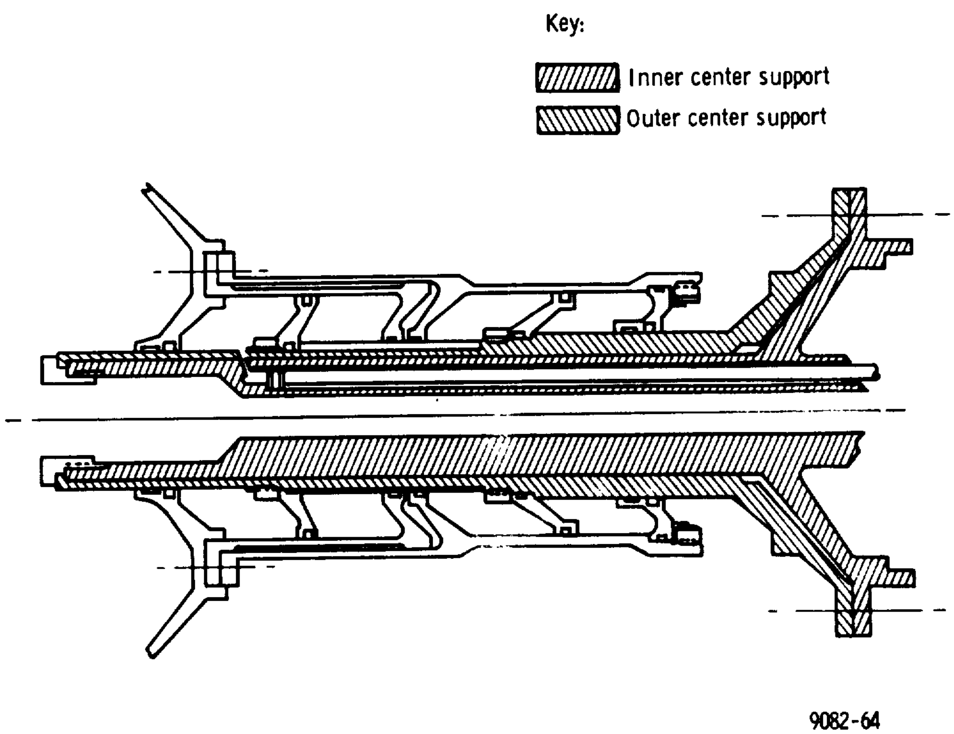

Figure 63. Redundant actuator support schematic.

Beta Regulator

Two Beta regulators, each operating on a separate hydraulic system, and each supplying fluid to separate chambers in the pitch change actuator, are used to provide redundancy. The Beta regulator assembly is shown in Figure 64, and the regulator is represented schematically in Figure 61. The design characteristics of the regulator are listed in Table XL.

TABLE XL. BETA REGULATOR CHARACTERISTICS

Flow, gal/min	10.9 (MIL-H-6083 at 180°F)
Supply pressure, psi	3000 (aircraft hydraulic system)
Temperature, °F	-65 to 275

The two Beta regulators are constructed with separate housings to prevent crack propagation between systems. Each regulator has an electro-hydraulic valve (EHV) to meter flow to the actuator in response to an input from the propulsion control computer. EHV spool position is monitored by a linear variable differential transformer (LVDT) to providc fault detection capability. A bypass valve is incorporated in each system to shut off the system in case of a malfunction in operation or loss of supply pressure. The bypass valve is spring loaded to the bypass position and is actuated to the operational position by a signal from the shutoff solenoid. A bypass indicating switch provides a signal to show that the valve has moved to the requested position. A differential pressure transducer for fault detection is incorporated to monitor the actuator differential pressure. This signal, when compared with the computer model of the EHV, will give an indication of actuator seal leakage and EHV spool valve condition.

SYSTEM WEIGHT SUMMARY

The fan system design was optimized to achieve a minimum system weight. Composite fan blades and a titanium fan case with integral gearbox housing have been incorporated to achieve the fan weights.

The following is a weight summary for the lift and lift/cruise fan systems:

	Lift fan (lb)	Lift/cruise fan (lb)
Rotor assembly	313	313
Beta regulator (total for 2)	11	11
Gear reduction assembly	328	---
Fan case	261	---
Total	913	324

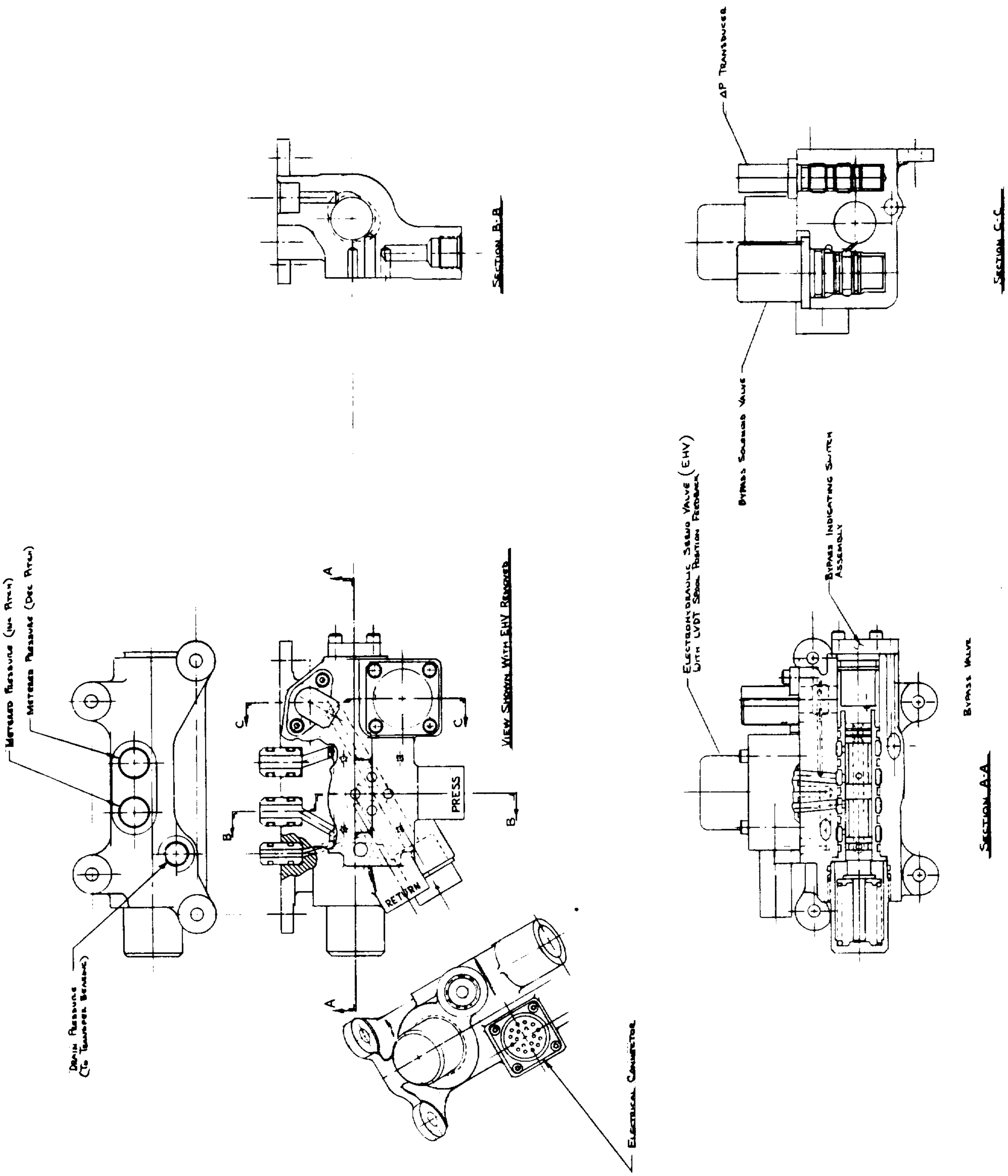

Figure 64. Beta regulator assembly.

These weights represent the fan systems in a "dry" condition. The fluids added to each system represent an addition of 15.0 lb for the lift fan and 1.5 lb for the lift/cruise fan.

The polar moments of inertia for the rotational components are 447.3 lb-ft^2 for the rotor and 48.2 lb-ft^2 for the gear reduction assembly.

LIFT/CRUISE ENGINE—FIXED NACELLE

GENERAL DESCRIPTION

The lift/cruise engine as designed for the fixed nacelle application is shown in cross section in Figure 65.

The turbofan engine system includes an XT701 shaft engine driving through an overrunning clutch to a star gearset. A 3.33:1 reduction is taken at the star gearset. Cross shaft output power is forward of the reduction gear. A 62-inch Hamilton Standard variable-pitch fan is located in front of the cross drive.

The cross drive and overrunning clutch arrangement allows power to be extracted from the lift/cruise engine or, in the case of a power section shutdown, the fan can be driven by power extracted from the cross drive.

The reduction gear shown is a direct adaptation of the T56-A-14 reduction gear components for which there is a lot of operating experience at torque levels comparable to the V/STOL requirements.

The overrunning clutch is a variant of the safety coupling that was designed for and tested in the T56-A-18 program.

Because the fan and gearbox assembly could be operative at times when the power section is shut down, a separate lubrication system is provided for the components in front of the overrunning clutch.

The fan Beta control, control valves, and electronic position feedback are located on the lift/cruise engine.

All rotating accessories required for the engine are located on an HP-driven accessory gearbox mounted between the primary and secondary flow paths. Provision is made for an airframe hydraulic pump and alternator drive.

GEARING

Reduction Gear Assembly

The reduction gear assembly designed for the PD370-25A is shown in Figure 66. This arrangement utilizes the sun gear, planet gears, planet gear bearings, and ring gear from the T56-A-14 and, when used in the manner shown, results in a 3.33:1 reduction ratio. The planet carrier shown in Figure 66 is a two-piece cast aluminum structure that incorporates the services for the variable-pitch fan.

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The operating stress levels for this gearset at the three-engine-operating design point of 8767 hp are as follows:

	Bending stress (psi)	Crushing stress (psi)
Sun gear mesh	15,000	133,000
Ring gear mesh	15,000	75,000

These stress levels are conservative and provide a high degree of reliability for the 500-hour required life.

Cross Shaft Gear Assembly

The cross shaft drive for the PD370-25A is shown in Figure 67. Power is extracted from a spiral bevel gear operating at fan speed. The cross shaft gear-to-pinion ratio is 3.33:1, which results in a pinion mechanical speed of 11,810 rpm at the design speed point.

The spiral bevel gear geometry and materials are shown in Figure 67. The gear stress levels for the design requirements are as follows:

	Normal takeoff	Max power out	Max power in
Horsepower	606	5045	6931
Pinion bending stress, psi	3000	25,000	34,400
Gear bending stress, psi	3000	23,200	31,900
Crushing stress, psi	70,600	203,600	238,600

The gear mount arrangement shown in Figure 67 provides a stiff support and allows a minimum of deflection under the most severe operating conditions.

BEARINGS

The bearings selected for the PD370-25A L/C gearbox are consistent with the practices followed by DDA for previous aircraft applications. Bearing locations, type, and materials are shown in Figures 66 and 67.

All the selected bearings incorporate one-piece steel separators, Class 5 tolerances, aircraft grade materials, and positive lubrication.

The reduction gear planet bearings are a spherical roller design taken directly from the T56-A-14. This design provides adequate life for the RTA V/STOL 500 hour requirement.

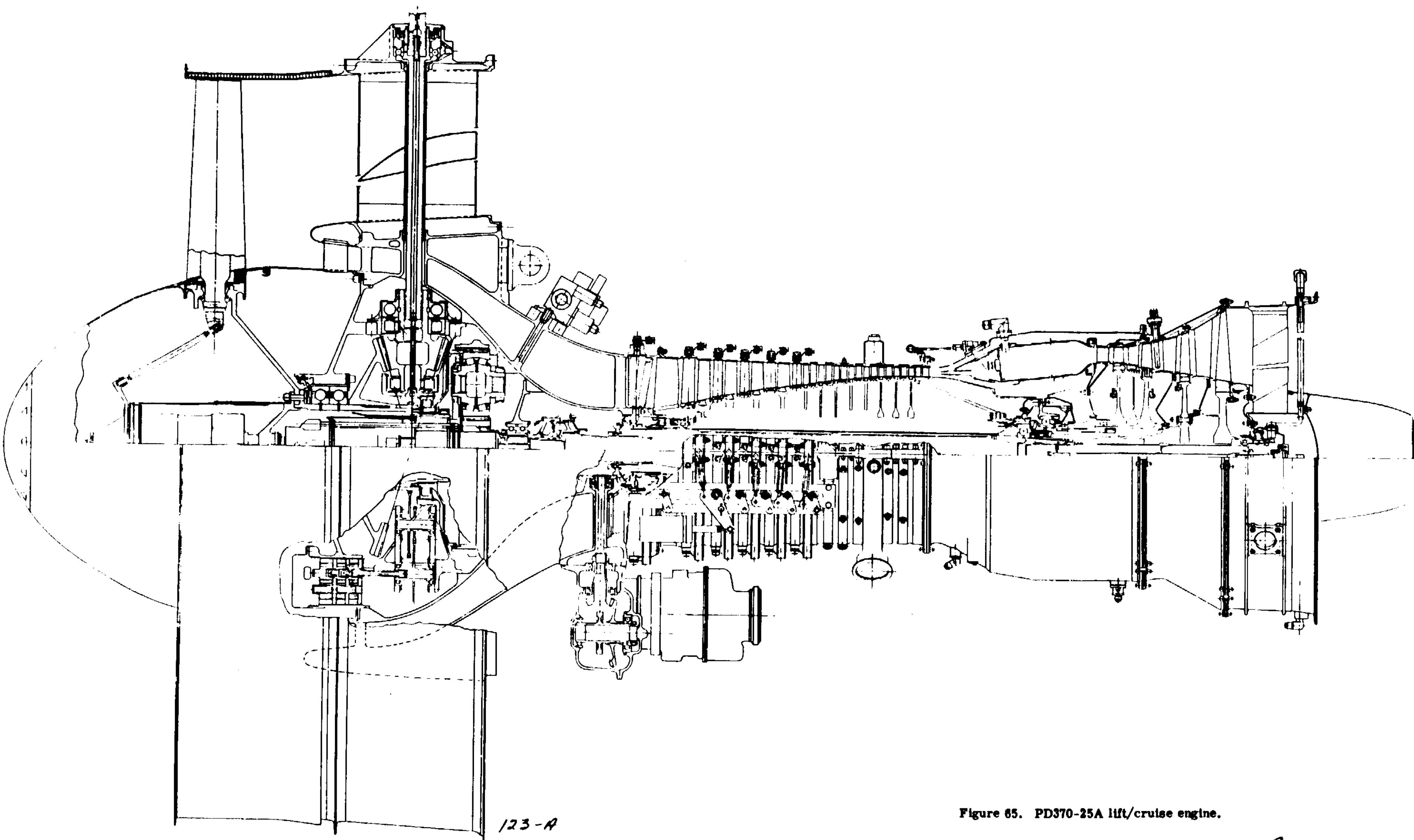

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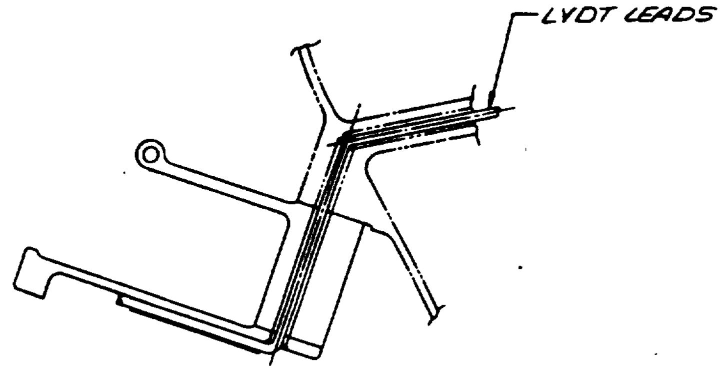
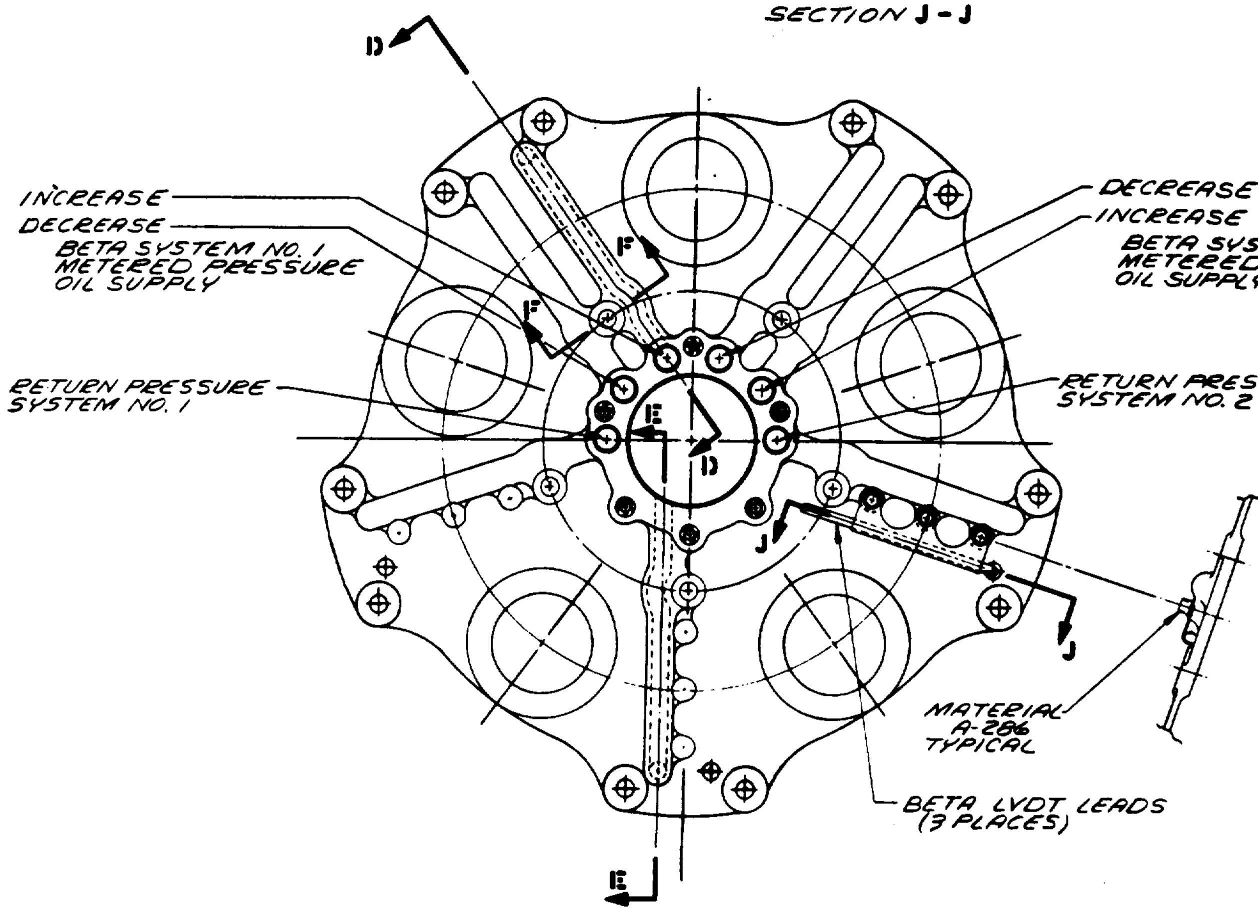
Figure 65. PD370-25A lift/cruise engine.

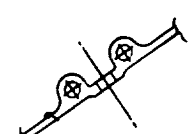
B



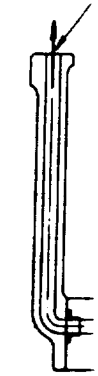
SECTION J - J



VIEW C

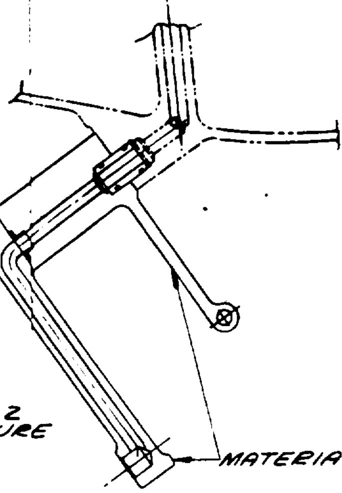


SECTION F - F



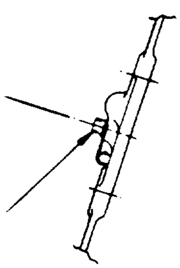
SECT.

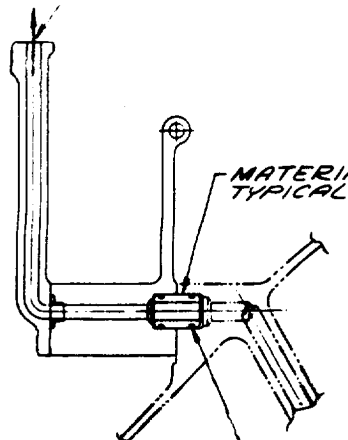
-LVDT LEADS



TURN PRESSURE
STEM NO. 2

SECTION D - D
TYPICAL 6 PLACES - BETA CONTROL
HYDRALIC SUPPLIES



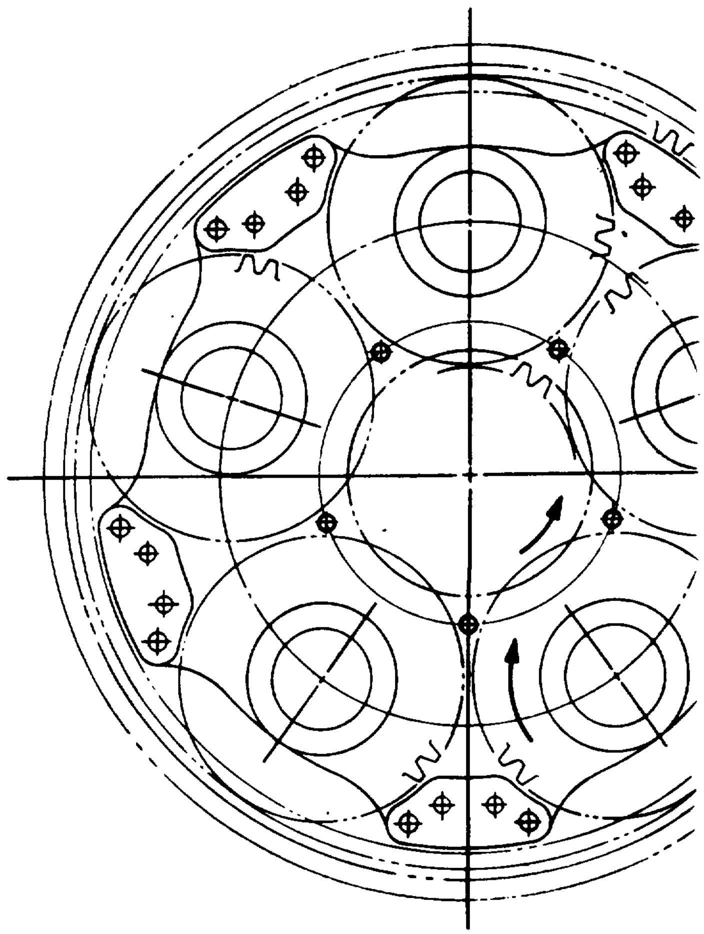


EADS

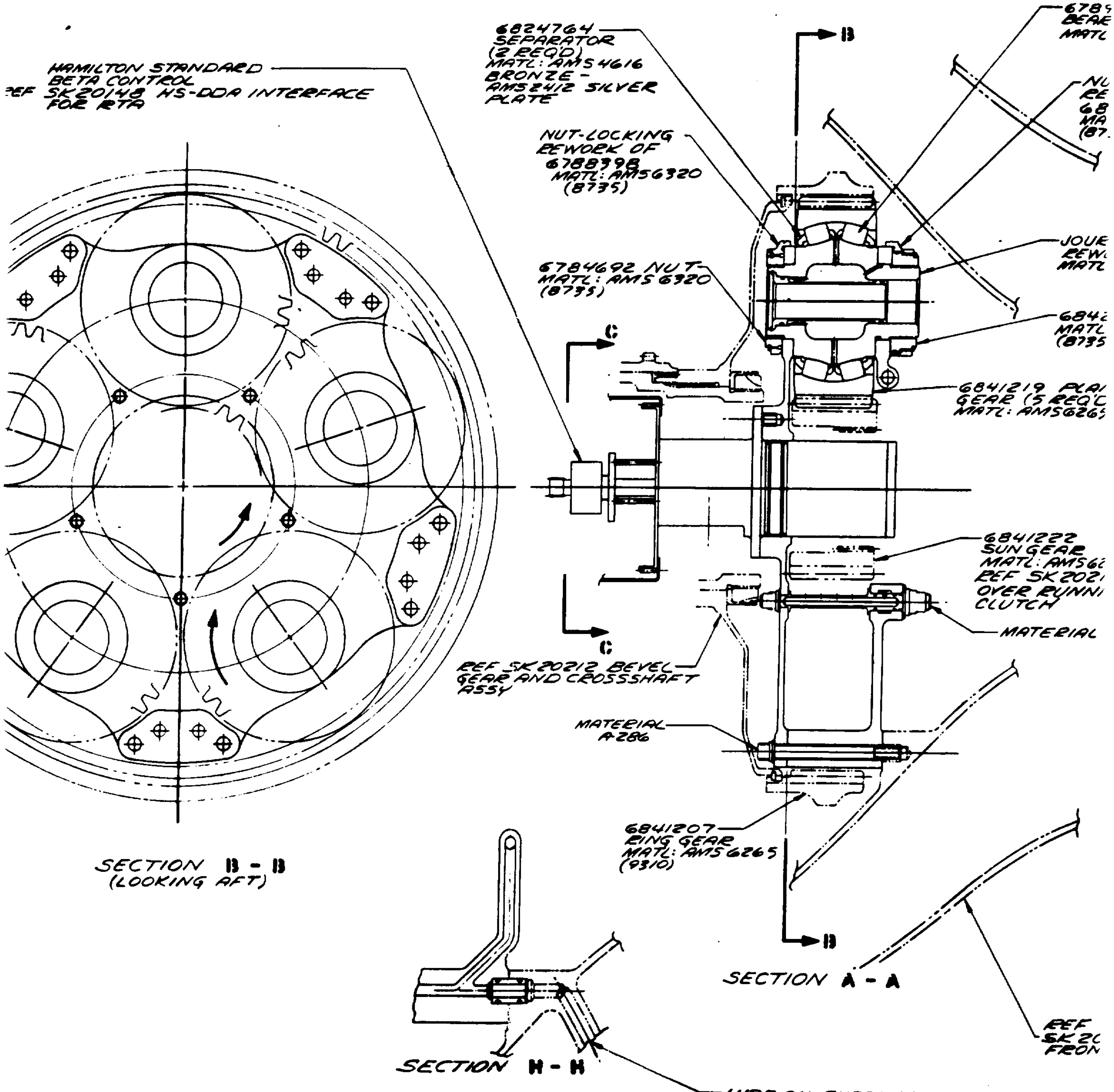
- F

SECTION E - E

HAMILTON STANDARD
BETA CONTROL
REF SK20148 HS-DDA INTERFAC
FOR RTA

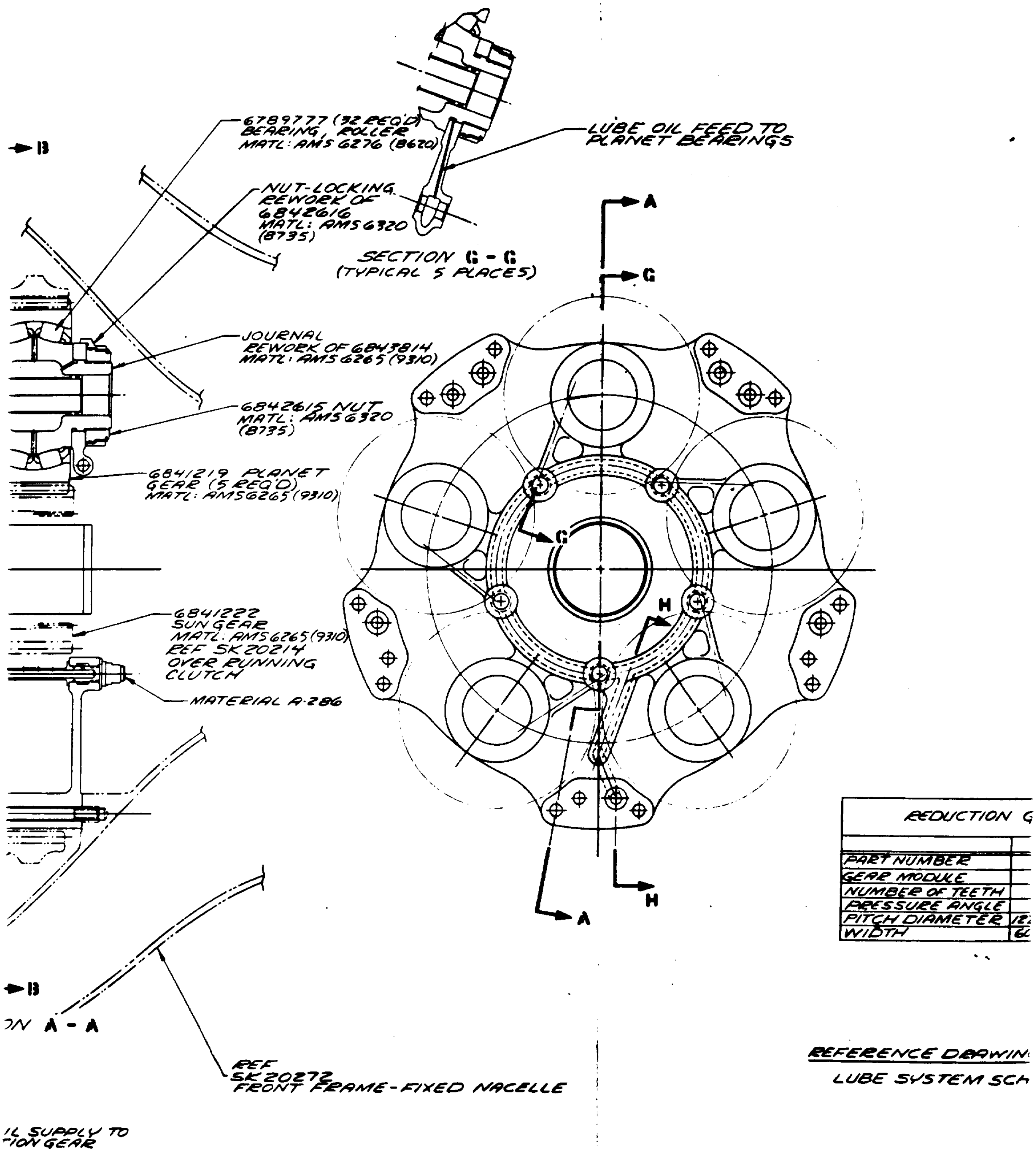


SECTION B - B
(LOOKING AFT)



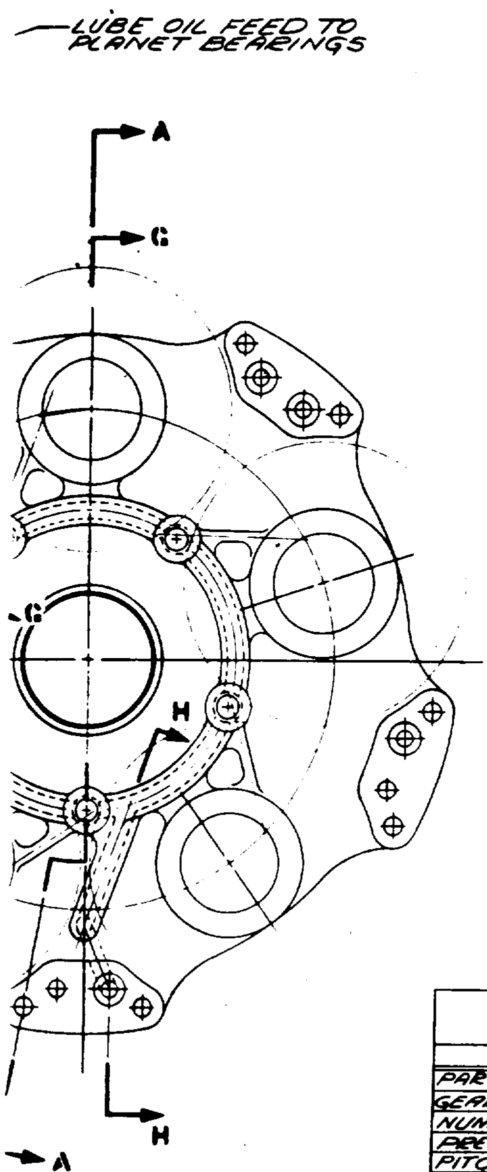
HAMILTON STANDARD BETA CONTROL
REF SK20148 HS-DDA INTERFACE FOR RTA
6824764 SEPARATOR (2 REQ'D) MATL: AMS 4616 BRONZE - AMS 2412 SILVER PLATE
NUT-LOCKING REWORK OF 6788398 MATL: AMS6320 (8735)
6784692 NUT- MATL: AMS 6320 (8735)
6841219 PLAN GEAR (5 REQ'D) MATL: AMS626
6841222 SUN GEAR MATL: AMS62 REF SK202 OVER RUNNI CLUTCH
MATERIAL
REF SK20212 BEVEL GEAR AND CROSSSHAFT ASSY
MATERIAL A286
6841207 RING GEAR MATL: AMS 6265 (9310)
SECTION B - B (LOOKING AFT)
SECTION A - A
SECTION H - H
LUBE OIL SUPPLY TO REDUCTION GEAR

3



125-C

Figure 66. PD37C



REDUCTION GEAR DATA	SUN	PLANET	RING
PART NUMBER	6841222	6841219	6841207
GEAR MODULE	4.2333	4.2333	4.2333
NUMBER OF TEETH	30	35	100
PRESSURE ANGLE	25	25	25
PITCH DIAMETER	127.00 [5.0000]	148.17 [5.8333]	423.33 [16.6667]
WIDTH	60.96 [2.400]	57.15 [2.250]	53.34 [2.100]

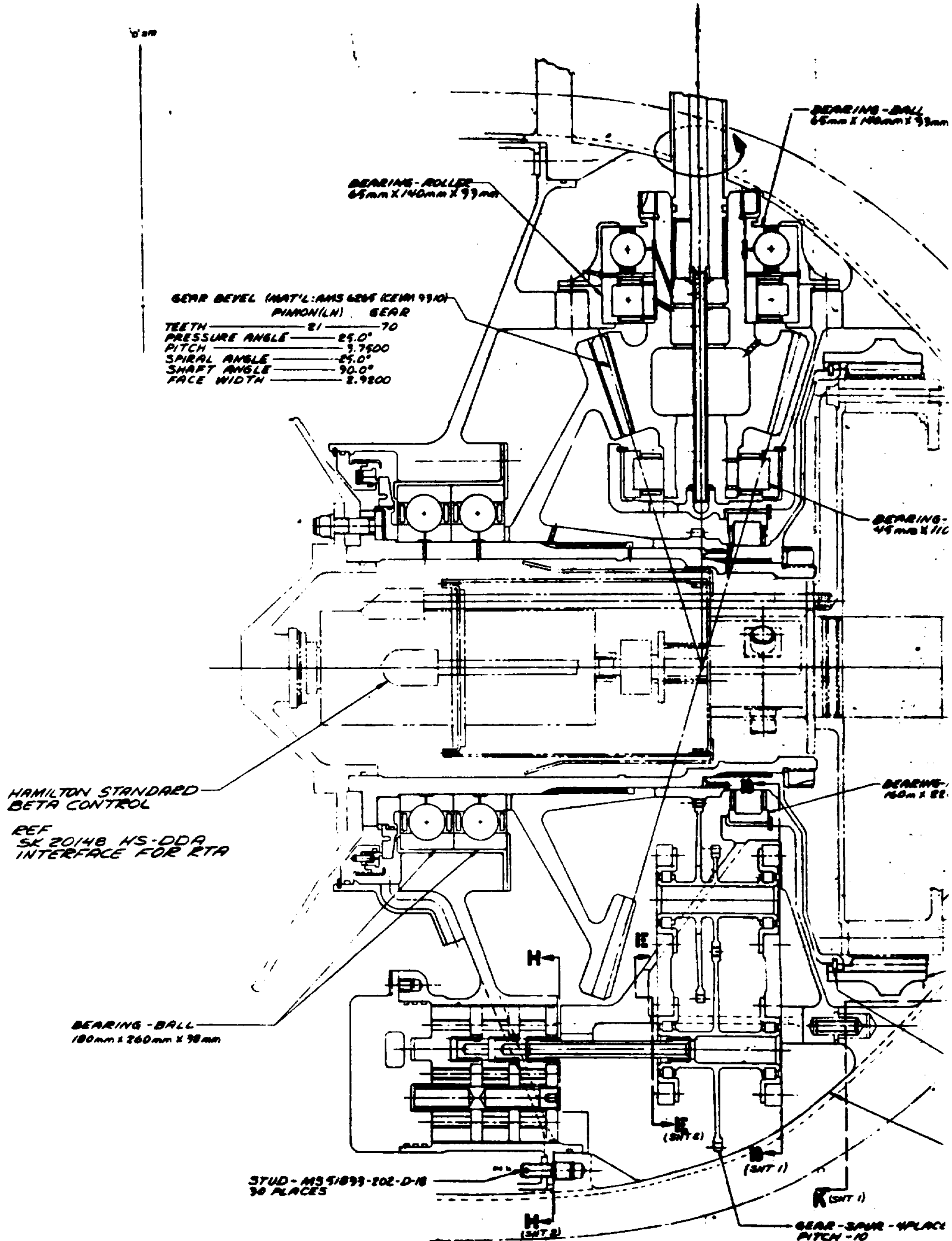
9082-67

REFERENCE DRAWING

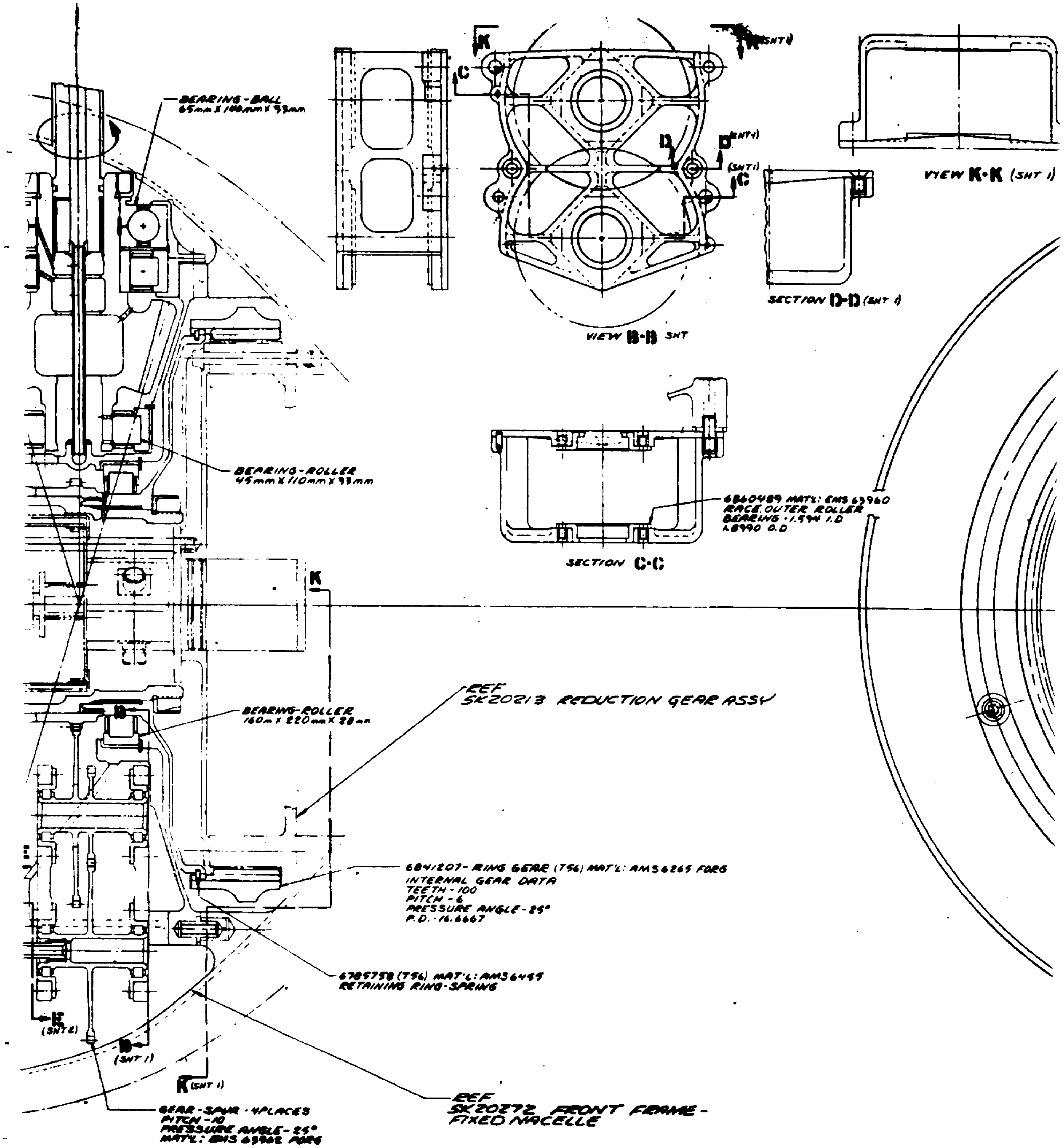
LUBE SYSTEM SCHEMATIC – SK 20280

ALL DIMENSIONS ON THIS DRAWING ARE EXPRESSED IN MILLIMETERS. DIMENSIONS IN [X.XXX] ARE EQUIVALENT INCHES

Figure 66. PD370-25A reduction gear assembly.

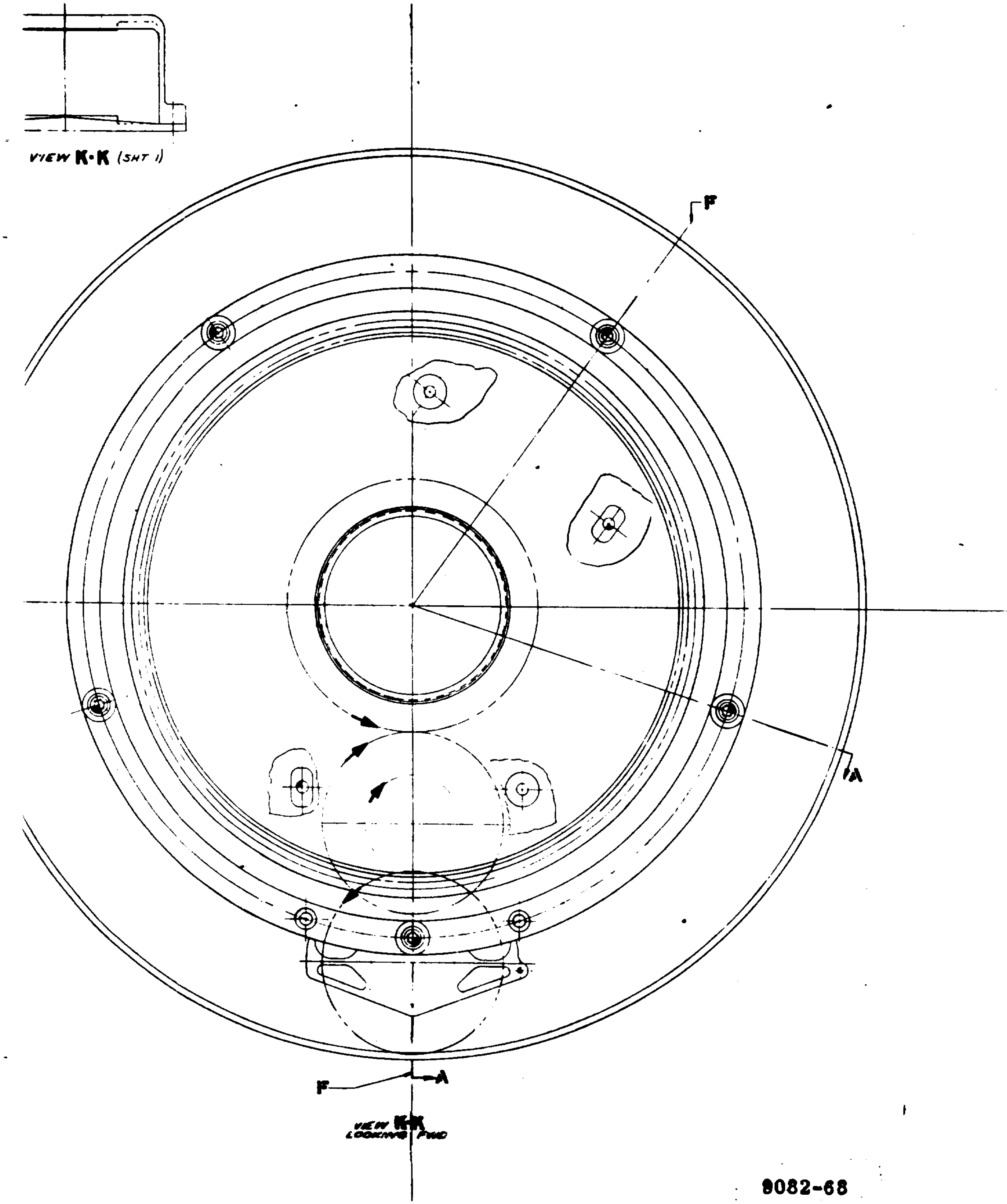

BEARING-BALL
65mm X 140mm X 33mm
BEARING-ROLLER
65mm X 140mm X 33mm
GEAR BEVEL (MAT'L: AMS 6265 (CEVM 9310)
PINION(LH) GEAR
TEETH 21 70
PRESSURE ANGLE 25.0°
PITCH 3.7500
SPIRAL ANGLE 25.0°
SHAFT ANGLE 90.0°
FACE WIDTH 2.9200
BEARING-
HAMILTON STANDARD
BETA CONTROL
REF
SK 20148 HS-DDA
INTERFACE FOR RTA
BEARING-
BEARING-BALL
180mm x 260mm x 98mm
STUD-MS 51833-202-D-18
30 PLACES
H
(SHT 2)
(SHT 1)
K (SHT 1)
GEAR-SPUR-4PLACE
PITCH-10
PRESSURE ANGLE-

SECTION A-A


BEARING-BALL
65mm X 140mm X 33mm
VIEW K-K (SHT 1)
SECTION D-D (SHT 1)
VIEW B-B SHT
BEARING-ROLLER
45mm X 110mm X 33mm
6860489 MAT'L: EMS 63960
RACE, OUTER ROLLER
BEARING - 1.594 I.D.
SECTION C-C
REF
SK20213 REDUCTION GEAR ASSY
BEARING-ROLLER
160m X 220mm X 28mm
6841207- RING GEAR (T56) MAT'L: AMS 6265 FORG
INTERNAL GEAR DATA
TEETH - 100
PITCH - 6
PRESSURE ANGLE - 25°
P.D. - 16.6667
6785758 (T56) MAT'L: AMS 6455
RETAINING RING-SPRING
REF
SK20272 FRONT FRAME-
FIXED NACELLE
GEAR-SPUR - 4 PLACES
PITCH - 10
PRESSURE ANGLE - 25°
MAT'L: EMS 63962 FORG

7-A

127-B



9082-68

Figure 67. PD370-25A cross shaft drive.

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OVERRUNNING CLUTCH

The overrunning clutch for the PD370-25A is shown in Figure 68. This clutch is a spring-loaded, hydraulically balanced, helical-splined coupling. The helix angle is such that in the normal mode of operation the coupling is forced into engagement. When a reverse torque is imposed on the coupling, the helical spline forces a disengagement and the hydraulic forces keep the coupling disengaged until the power section is brought back to speed.

The following are the coupling geometry and stress levels:

Spline size	8/16
Pitch diameter, in.	4.75
Length, in.	0.3
Torque at max power, in.-lb	48,400
Spline stress at max power, psi	14,300

The overrunning clutch is identical in operation with the T56-A18 clutch except in the source of the oil for antiratcheting. The oil in the aft annulus will be provided by the power section, and the oil retained by the forward cup will be provided by the L/C gearbox supply. When the power section oil supply is removed (as in the case of a power section failure) and the clutch uncouples, the oil drains from the aft cup. The pressure generated in the forward cup drives the outer splined coupling to the left and prevents ratcheting until the power section becomes operable and the oil is restored to the aft cup. When the power section oil is restored, the Belleville springs can move the outer coupling to the right and reengage the clutch.

FAN DRIVE AND INTERFACES

The fan drive and actuator interfaces with the L/C gearbox are shown in Figure 69.

Two separate hydraulic systems for fan Beta control are incorporated in the L/C gearbox. The Beta control regulators are mounted on the fan case structure between the primary and secondary flow paths as noted previously. Increase and decrease hydraulic oil is routed from the regulators to the actuator through the main fan support and the reduction gear planet carrier. (See Figure 66.)

The LVDT signal cables are routed through the reduction gear and frame in the same manner as the hydraulic lines.

STRUCTURE—MOUNTS

The front structural member of this "fixed" lift/cruise engine is the cast aluminum inner frame. This component, which is shown in cross section in Figure 70, includes two pairs of mounting

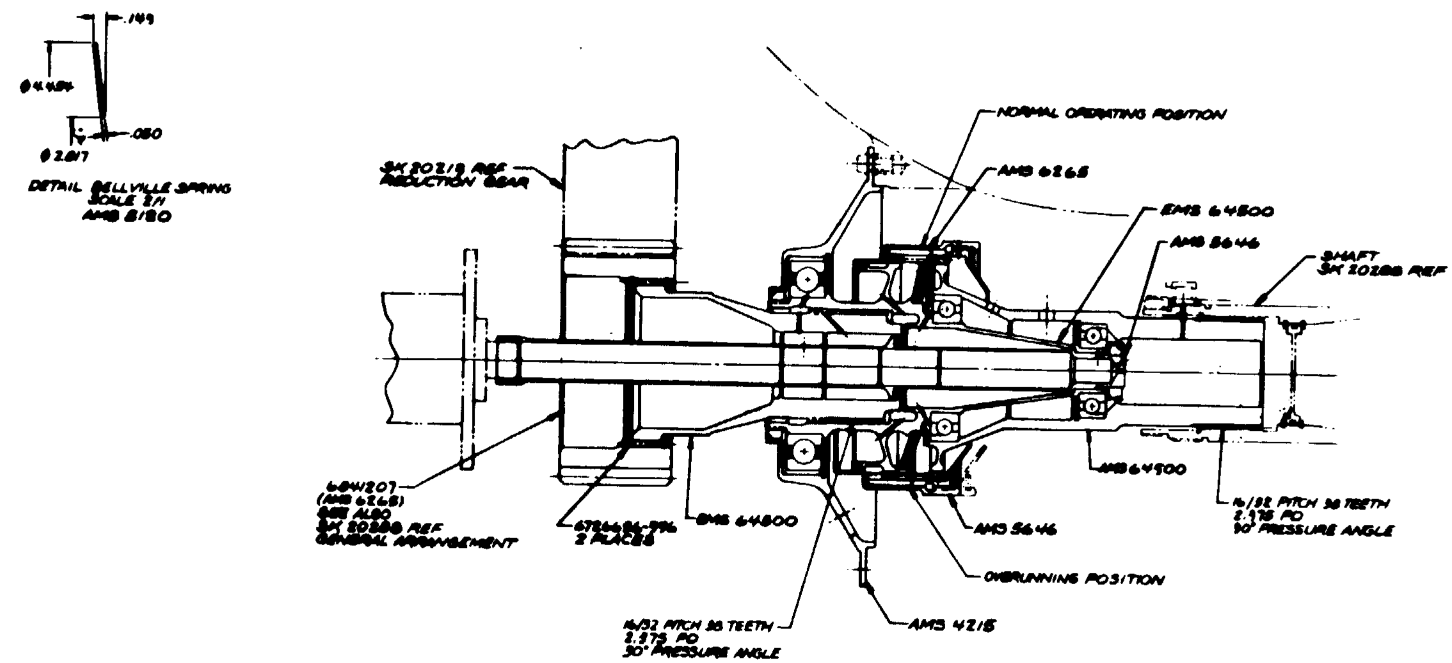
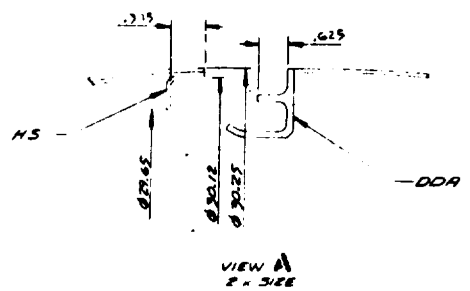
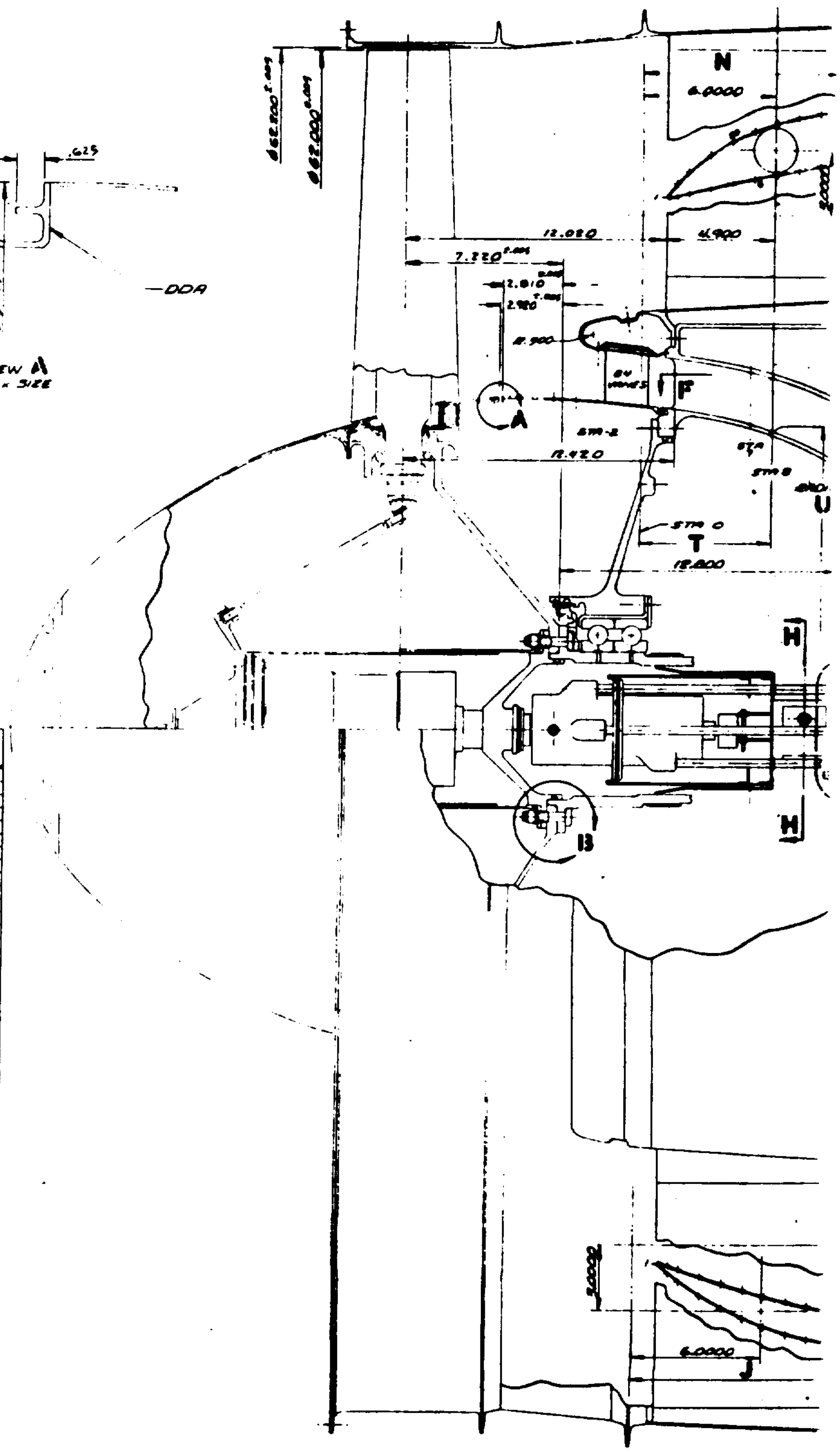
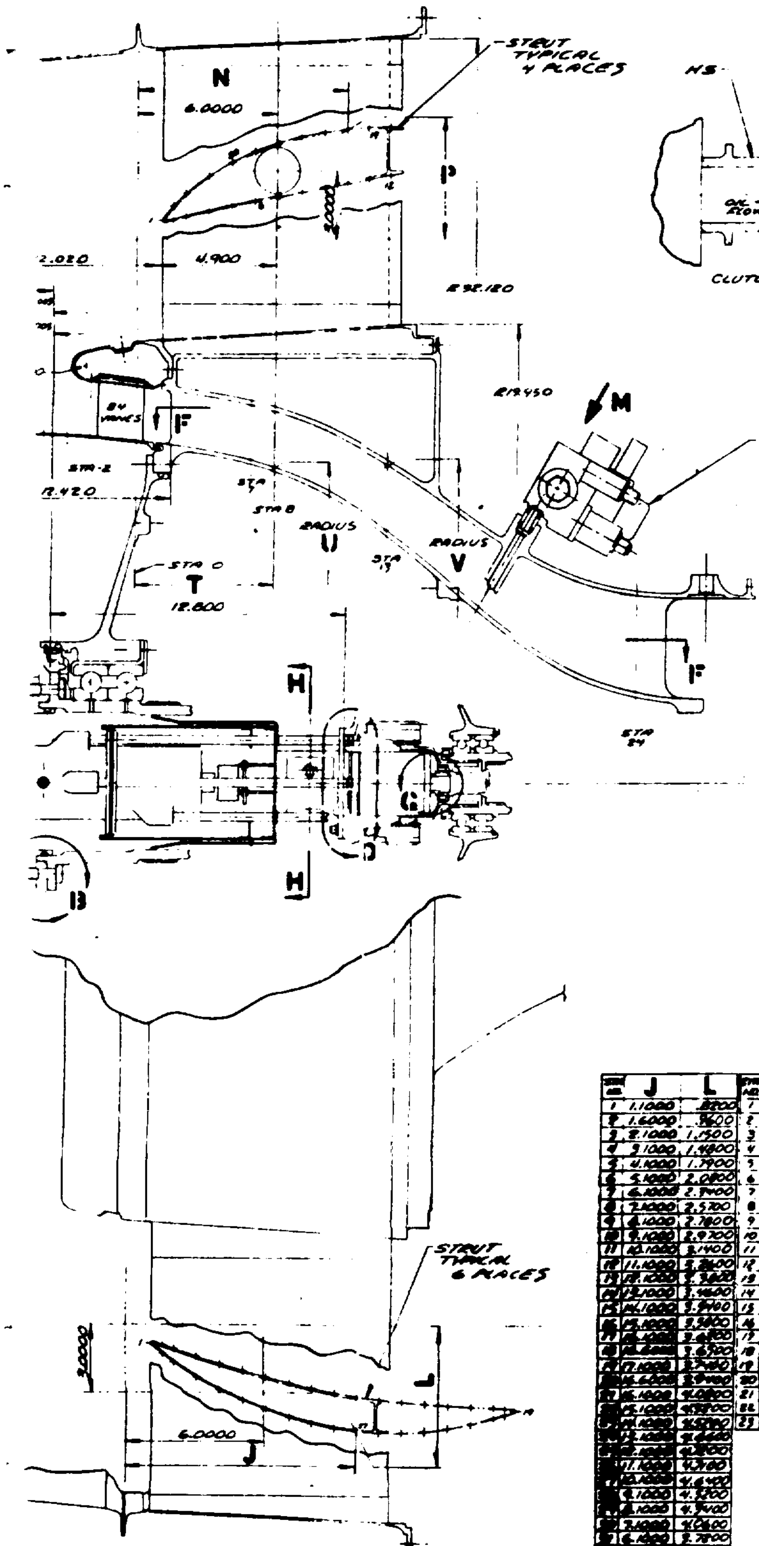


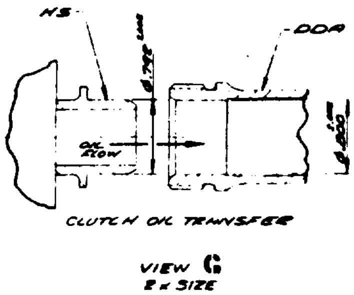
Figure 68. PD370-25A overrunning clutch.

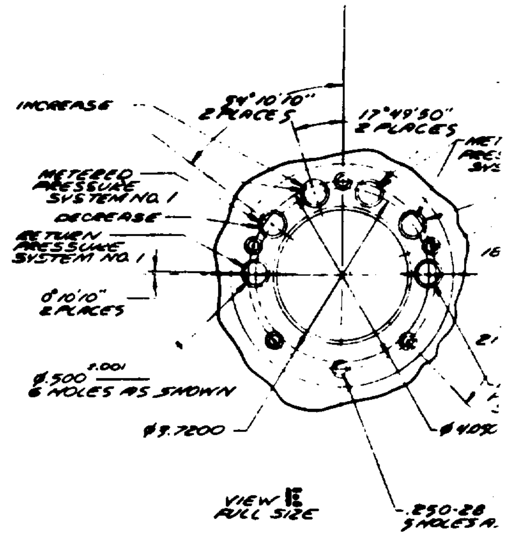


STA NO.	T	RADIUS U	RADIUS V
-6	-6.0000	15.1500	———
-5	-5.0000	15.1700	———
-4	-4.0000	15.1800	———
-3	-3.0000	15.1700	———
-2	-2.0000	15.1400	17.3100
-1	-1.0000	15.0900	17.3000
0	.0000	15.0300	17.2800
1	.5000	15.0000	17.2700
2	1.0000	14.9700	17.2600
3	1.5000	14.9300	17.2400
4	2.0000	14.9100	17.2300
5	3.0000	14.8300	17.1800
6	4.0000	14.7000	17.0900
7	5.0000	14.5000	16.9100
8	6.0000	14.2100	16.6800
9	7.0000	13.8000	16.3700
10	8.0000	13.3000	15.9200
11	9.0000	12.6100	15.3400
12	10.0000	11.8000	14.7100
13	11.0000	10.8400	14.0400
14	12.0000	9.7600	13.3500
15	13.0000	8.6600	12.6500
16	14.0000	7.6100	11.9700
17	15.0000	6.6000	11.3100
18	16.0000	5.7400	10.7000
19	17.0000	5.0400	10.1400
20	18.0000	4.5000	9.6200
21	19.0000	4.0900	9.1600
22	20.0000	3.8400	8.7600
23	21.0000	3.7000	8.4100
24	22.0000	3.6300	8.2600
25	23.0000	3.6000	7.9900
26	24.0000	3.6000	7.8800

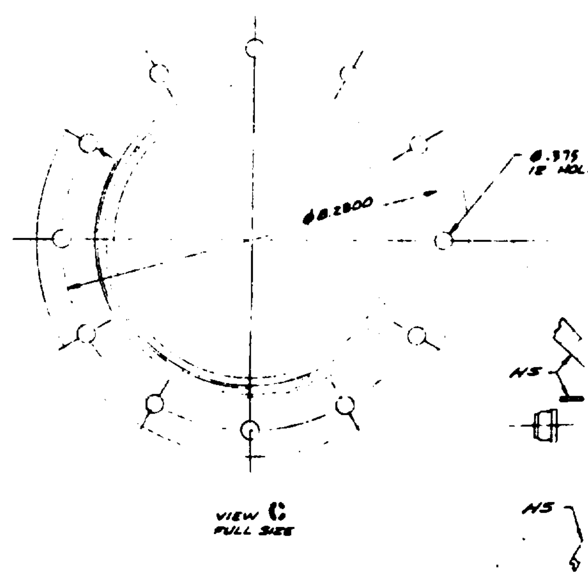




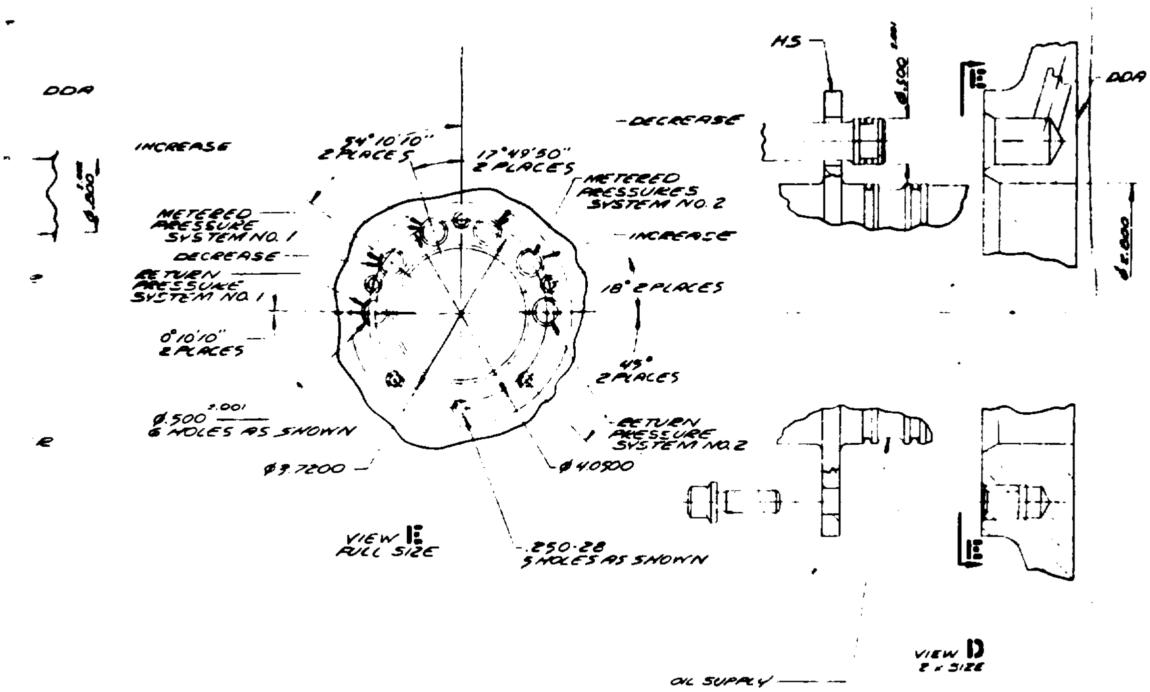


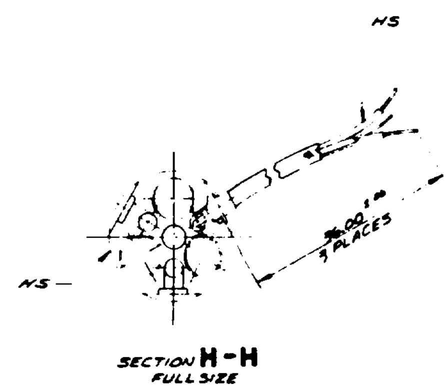


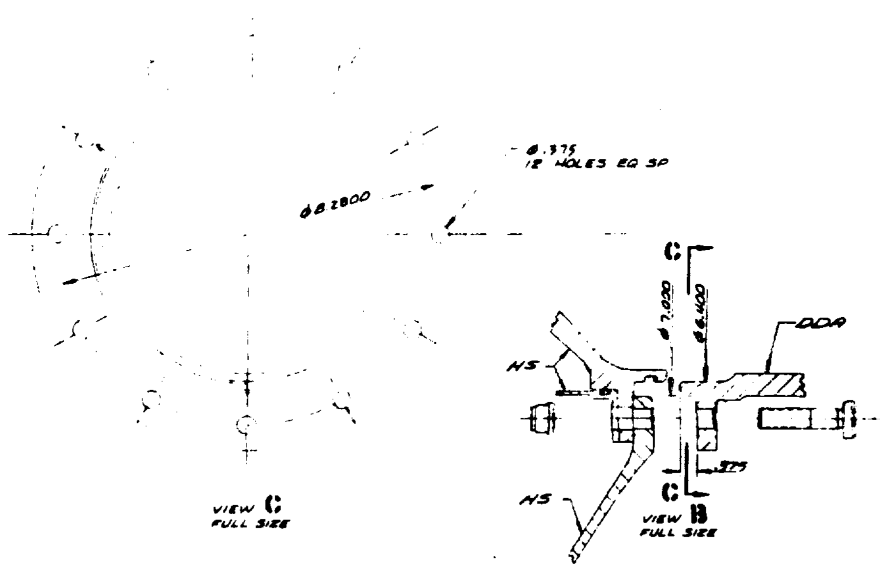
STA NO.	J	L	STA NO.	N	P
1	1.1000	.8200	1	1.1000	.8200
2	1.6000	.9600	2	1.6000	.9200
3	2.1000	1.1500	3	2.1000	1.0400
4	3.1000	1.4800	4	3.1000	1.2500
5	4.1000	1.7900	5	4.1000	1.4800
6	5.1000	2.0800	6	5.1000	1.7000
7	6.1000	2.3400	7	6.1000	1.9200
8	7.1000	2.5700	8	7.1000	2.1500
9	8.1000	2.7800	9	8.1000	2.3100
10	9.1000	2.9700	10	9.1000	2.5900
11	10.1000	3.1400	11	10.1000	2.7500
12	11.1000	3.2800	12	11.1000	2.8600
13	12.1000	3.3800	13	12.1000	5.1200
14	13.1000	3.4600	14	10.1000	5.0400
15	14.1000	3.5400	15	9.1000	4.9100
16	15.1000	3.5800	16	8.1000	4.7200
17	[illegible]	3.6100	17	7.1000	4.4900
[illegible]	[illegible]	3.6300	18	6.1000	4.1900
[illegible]	17.1000	3.7400	19	5.1000	3.7900
[illegible]	16.6000	3.9400	20	4.1000	3.2800
[illegible]	16.1000	4.0800	21	3.1000	2.8600
[illegible]	15.1000	[illegible]	22	2.1000	1.7700
[illegible]	14.1000	[illegible]	23	1.6000	1.3500
[illegible]	13.1000	[illegible]			
[illegible]	12.1000	4.7800			
[illegible]	7.1000	4.7100			
[illegible]	10.1000	4.6400			
[illegible]	9.1000	4.5200			
[illegible]	8.1000	4.3400			
[illegible]	7.1000	4.0600			
[illegible]	6.1000	3.7800			
[illegible]	5.1000	3.3700			
[illegible]	4.1000	2.8400			
[illegible]	3.1000	2.3900			
[illegible]	2.1000	1.6200			
[illegible]	1.1000	1.3100			



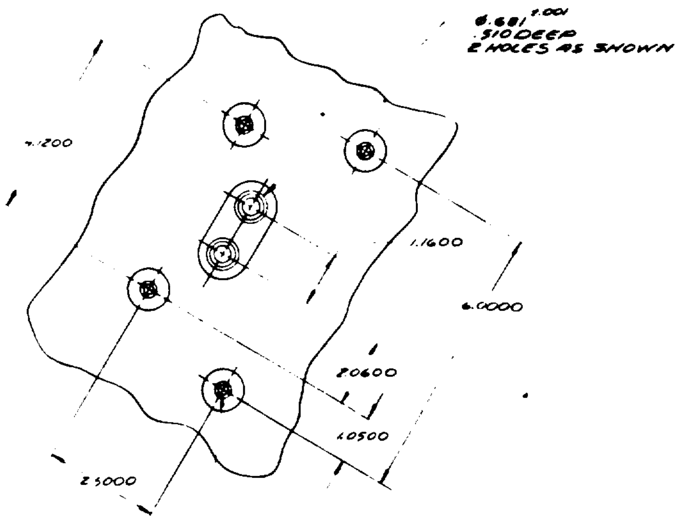
131-A


DDA
INCREASE
54°10'10"
2 PLACES
17°49'50"
2 PLACES
METERED PRESSURES SYSTEM NO. 2
METERED PRESSURE SYSTEM NO. 1
DECREASE
INCREASE
RETURN PRESSURE SYSTEM NO. 1
18° 2 PLACES
0°10'10"
2 PLACES
45°
2 PLACES
Ø.500 ±.001
6 HOLES AS SHOWN
RETURN PRESSURE SYSTEM NO. 2
Ø3.7200
Ø4.0500
VIEW E
FULL SIZE
.250-28
3 HOLES AS SHOWN
HS
DECREASE
DDA
Ø2.800
VIEW D
2 x SIZE
OIL SUPPLY


HS
HS
3 PLACES
SECTION H-H
FULL SIZE


Ø.375
12 HOLES EQ SP
Ø8.2800
VIEW C
FULL SIZE
C
C
Ø7.020
Ø6.400
DDA
HS
HS
.375
VIEW B
FULL SIZE

131-B

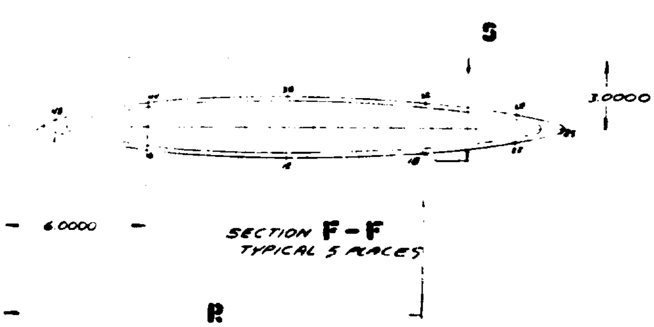


VIEW ON ARROW **M**
FULL SIZE

BETA REGULATOR MOUNT PAD
2 PLACES

HS

STA NO.	R	S
1	1.5000	3.0000
2	2.0000	3.2700
3	3.0000	3.5000
4	4.0000	3.7000
5	5.0000	3.8800
6	6.0000	4.0200
7	7.0000	4.1200
8	8.0000	4.2400
9	9.0000	4.3000
10	10.0000	4.3400
11	11.0000	4.3600
12	12.0000	4.3600
13	13.0000	4.3400
14	14.0000	4.3200
15	15.0000	4.2300
16	16.0000	4.2100
17	17.0000	4.1300
18	18.0000	4.0500
19	19.0000	3.9600
20	20.0000	3.8600
21	21.0000	3.7500
22	22.0000	3.6300
23	23.0000	3.4500
24	23.5000	3.3500
25	24.0800	3.0000
26	23.5000	2.6700
27	23.0000	2.5500
28	22.0000	2.3700
29	21.0000	2.2500
30	20.0000	2.1400
31	19.0000	2.0400
32	18.0000	1.9500
33	17.0000	1.8700
34	16.0000	1.7900
35	15.0000	1.7300
36	14.0000	1.6800
37	13.0000	1.6600
38	12.0000	1.6400
39	11.0000	1.6400
40	10.0000	1.6600
41	9.0000	1.7000
42	8.0000	1.7600
43	7.0000	1.8600
44	6.0000	1.9800
45	5.0000	2.1200
46	4.0000	2.3000
47	3.0000	2.5000
48	2.0000	2.7300

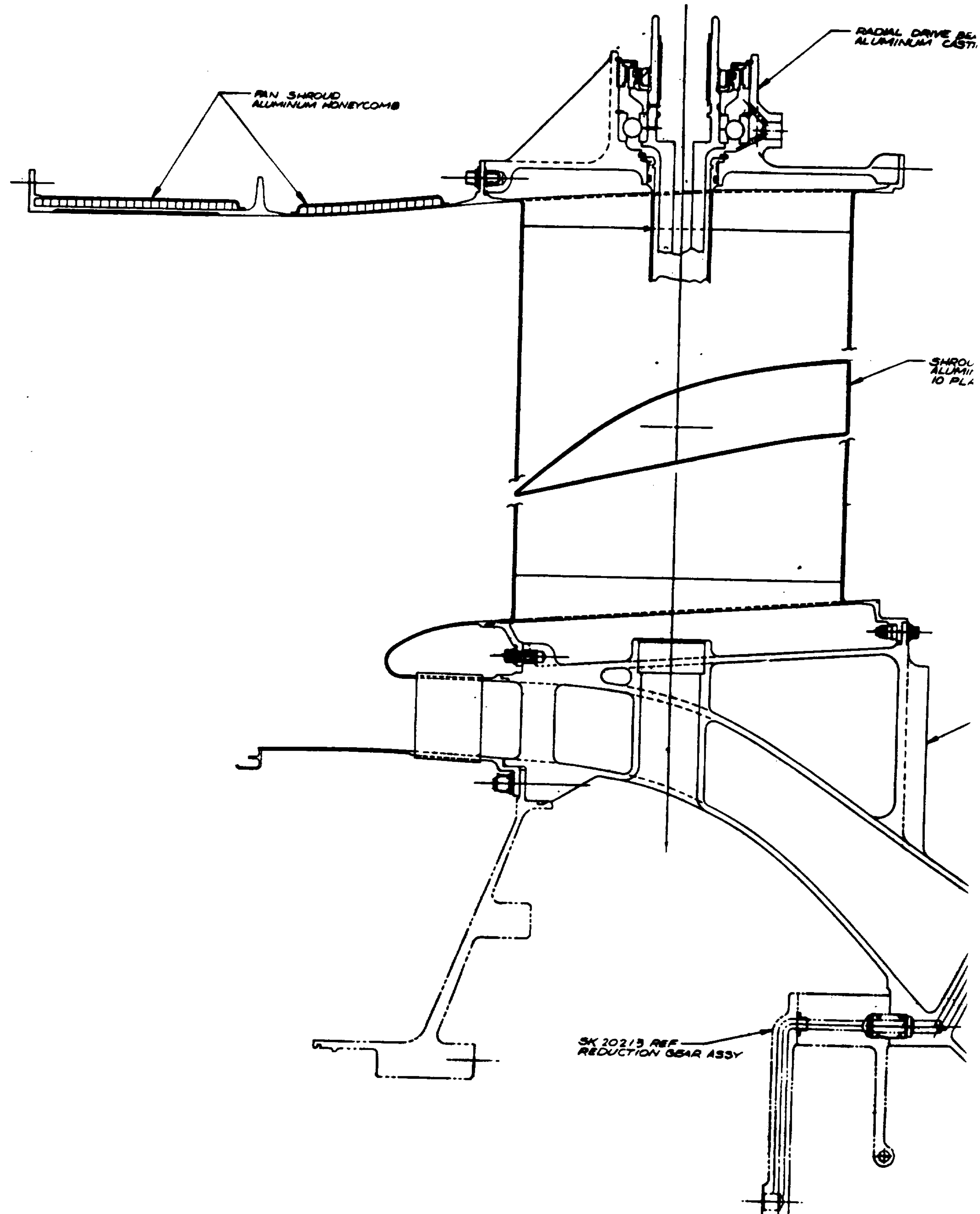


SECTION **F-F**
TYPICAL 5 PLACES

9082-70

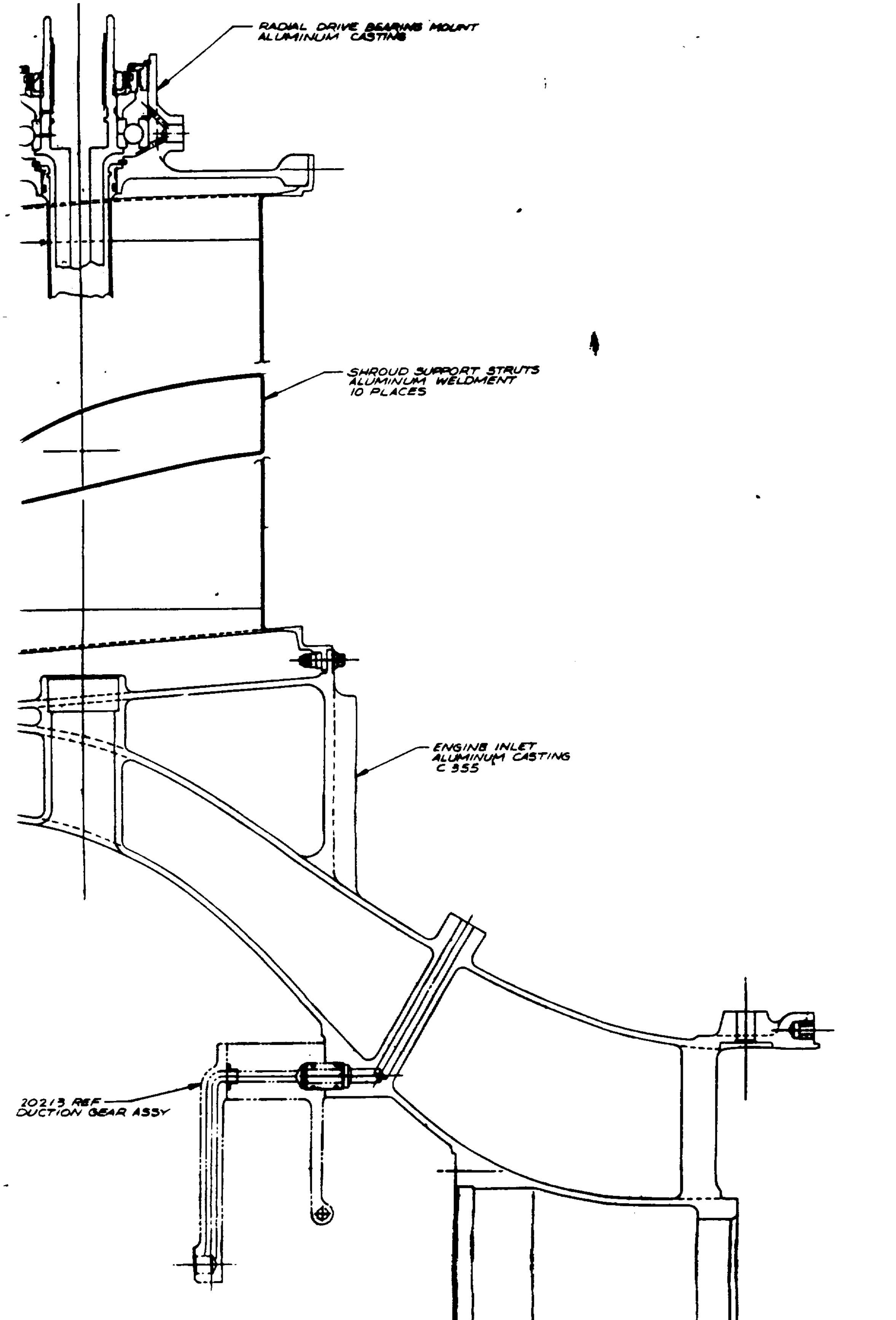
HS - HAMILTON STANDARD
DDA - DETROIT DIESEL ALLISON

Figure 69. DDA-HS interface for RTA.



FAN SHROUD
ALUMINUM HONEYCOMB
RADIAL DRIVE BE
ALUMINUM CASTI
SHROU
ALUMI
10 PLA
SK 20213 REF
REDUCTION GEAR ASSY

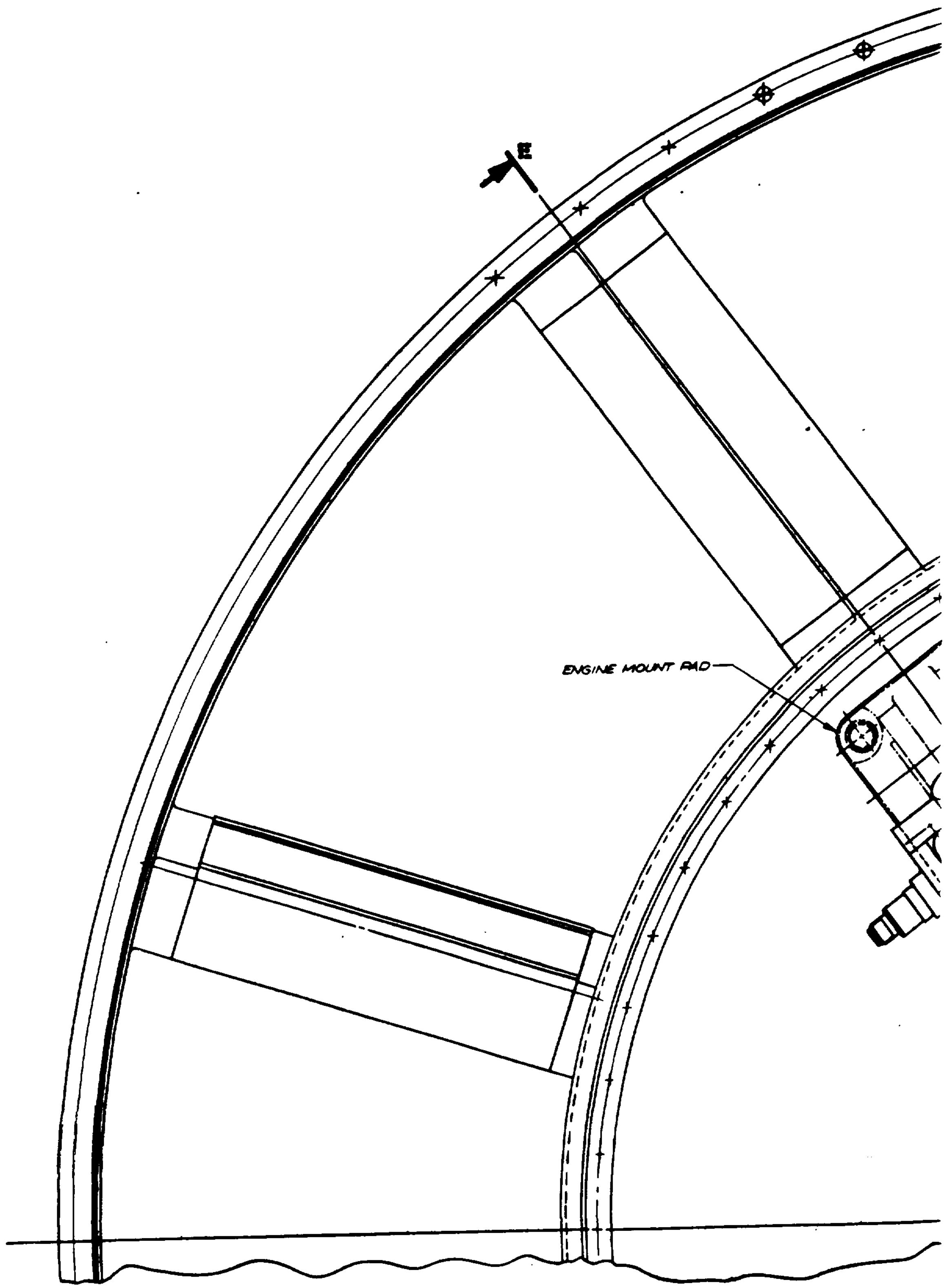
SECTION B-B



RADIAL DRIVE BEARING MOUNT
ALUMINUM CASTING
SHROUD SUPPORT STRUTS
ALUMINUM WELDMENT
10 PLACES
ENGINE INLET
ALUMINUM CASTING
C 355
20213 REF
DUCTION GEAR ASSY

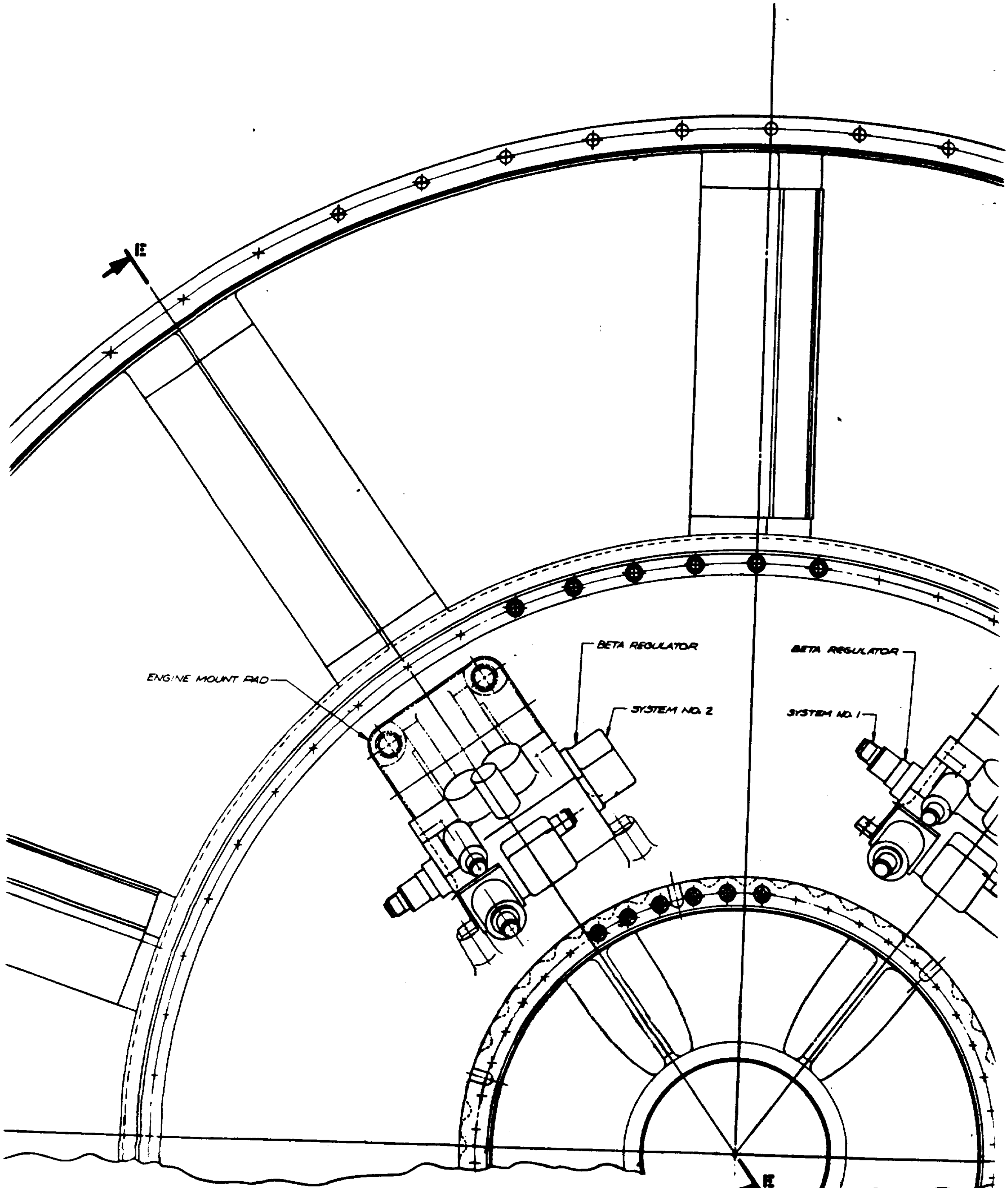
:TION B - B

133-B



-B

133-C


E
ENGINE MOUNT PAD
BETA REGULATOR
SYSTEM NO. 2
BETA REGULATOR
SYSTEM NO. 1
E

133-C

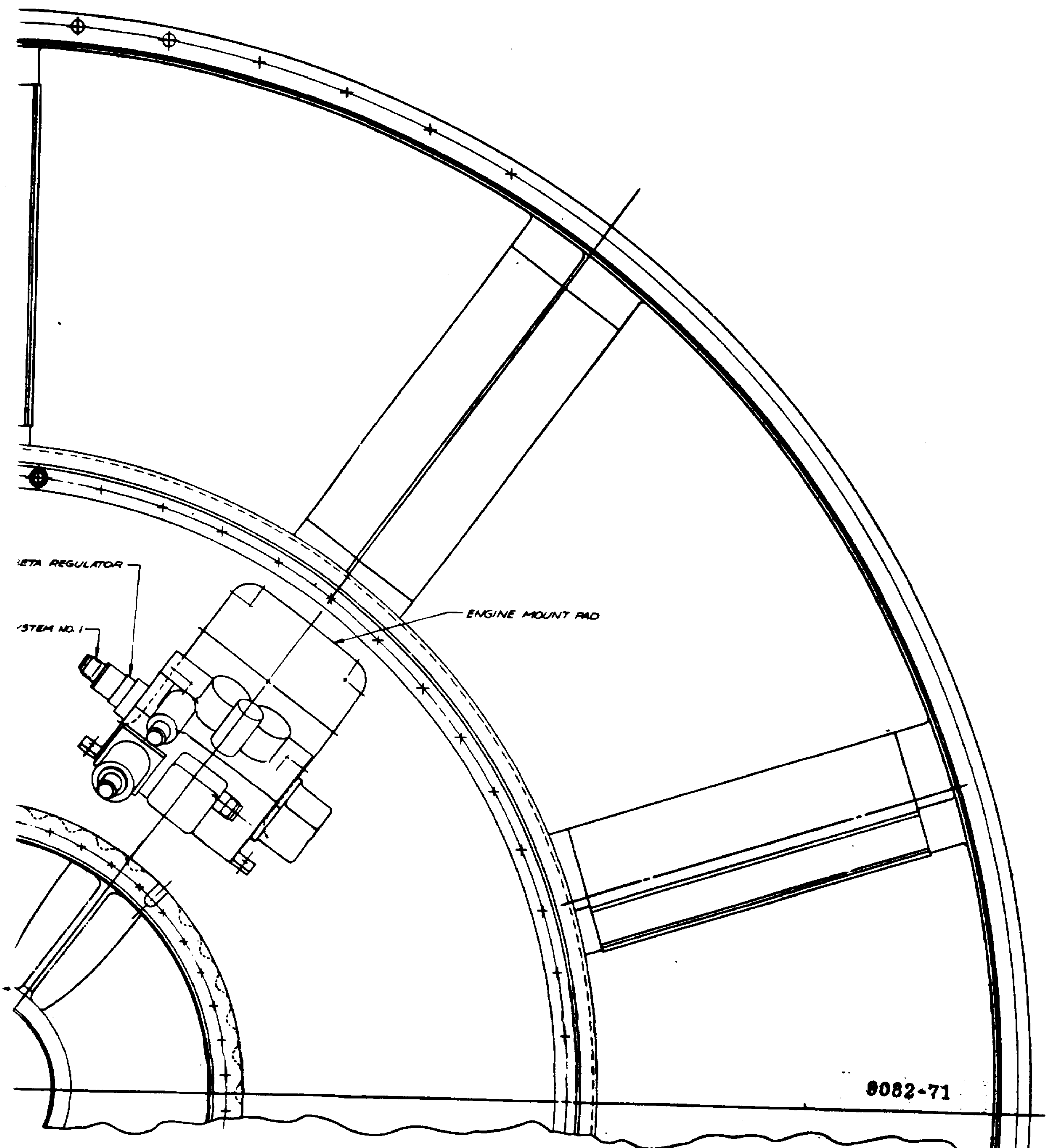


Figure 70. PD370-25A front frame (sheet 1 of 3).

D

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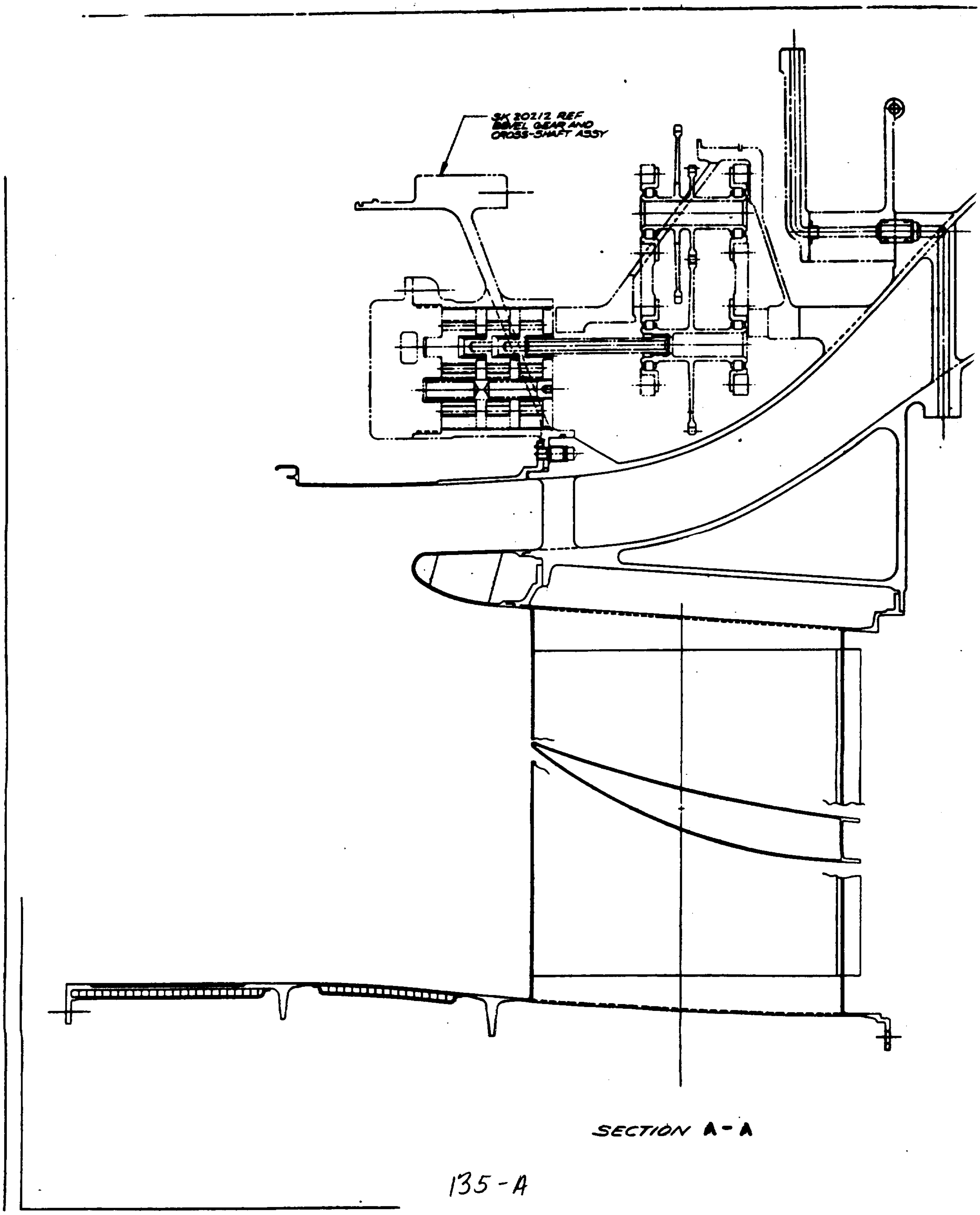
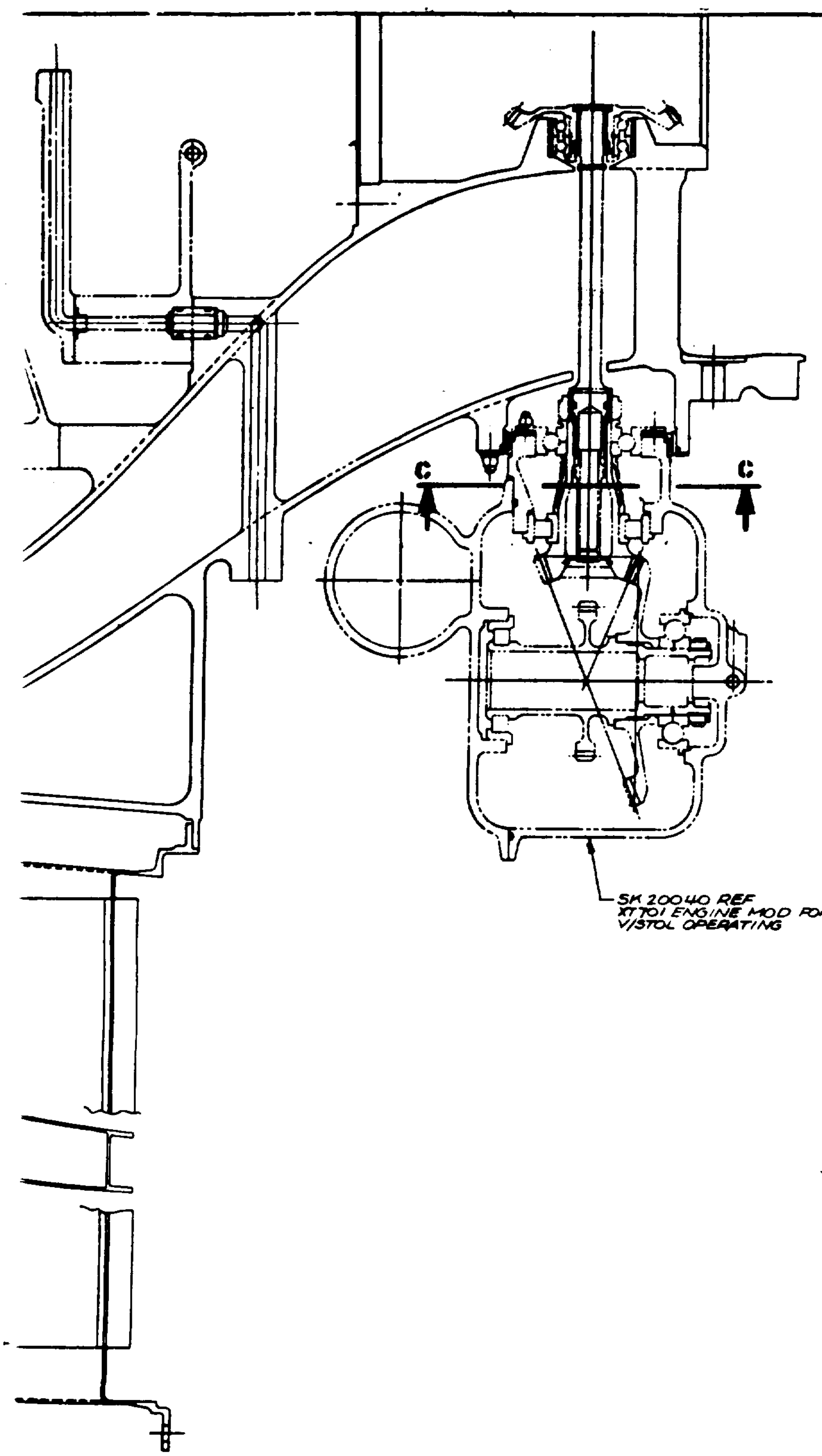
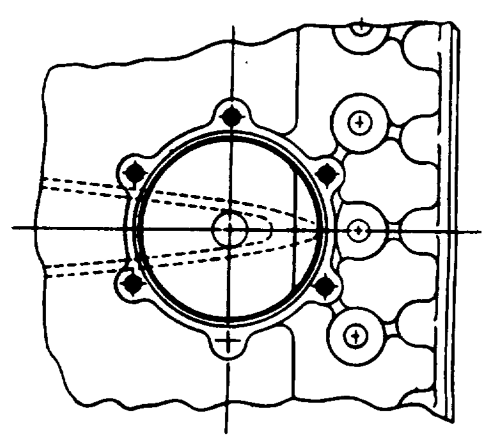


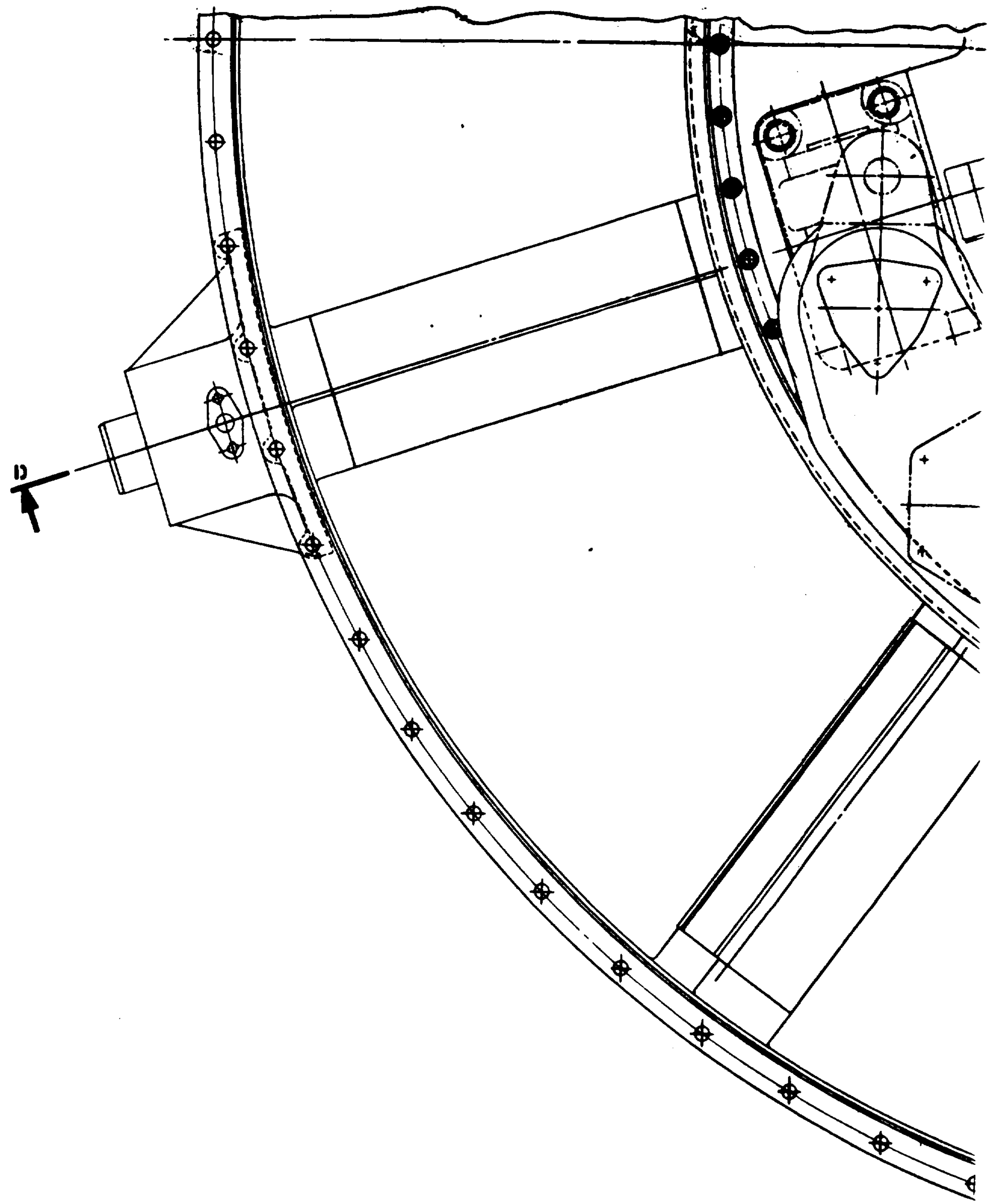
SECTION A - A

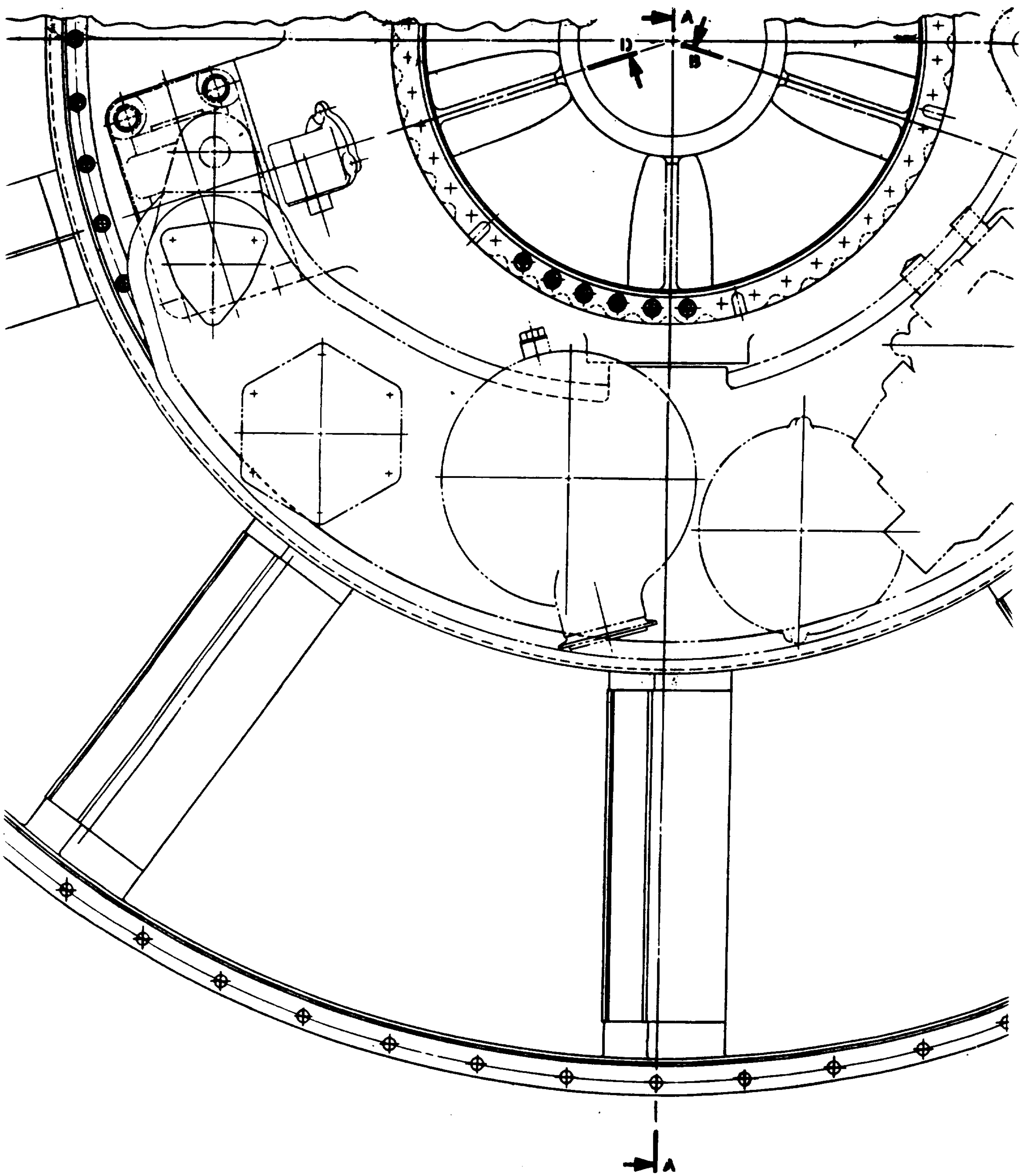




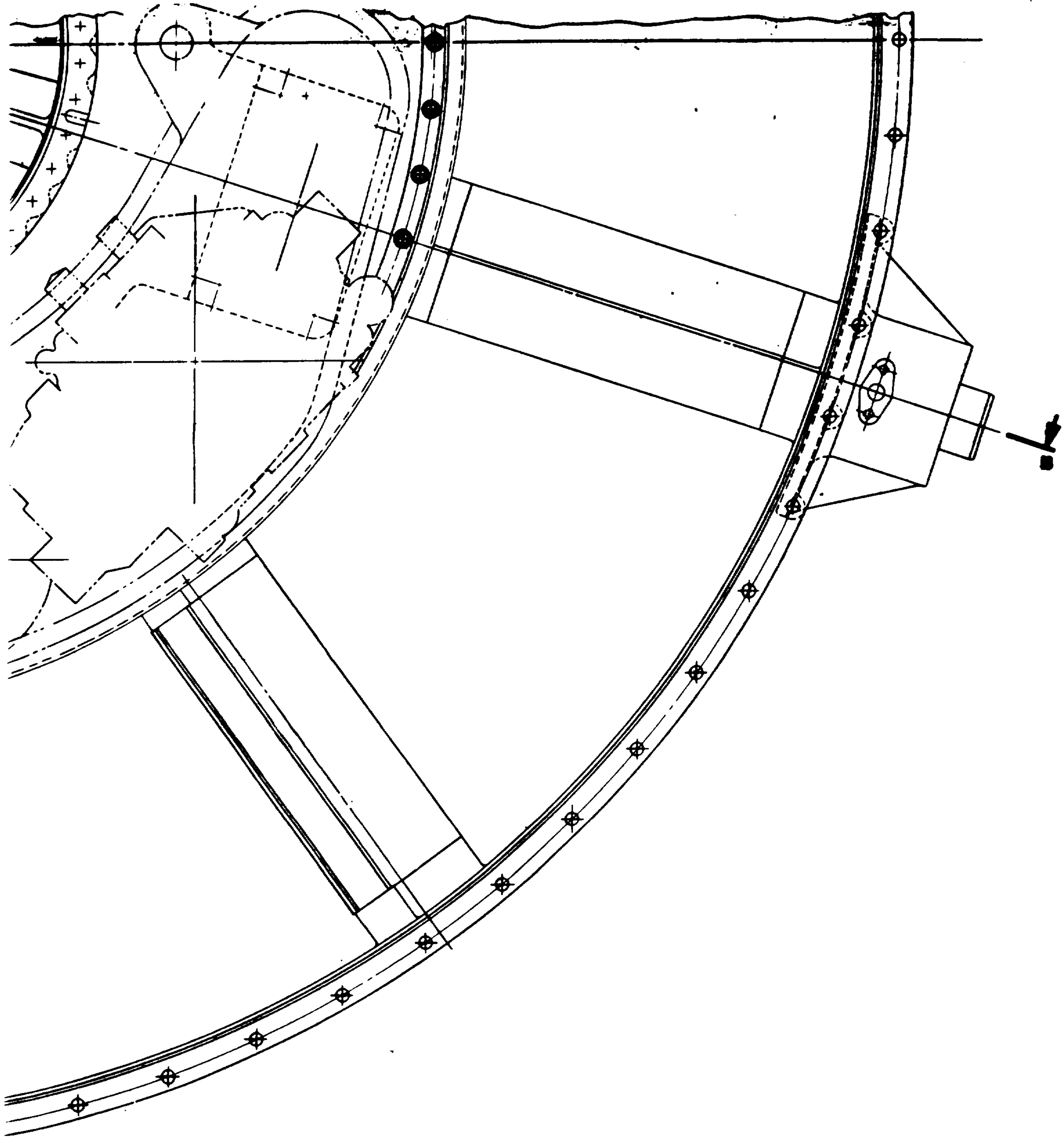
SECTION C - C

135-B


D



135-D



9082-72

Figure 70. PD370-25A front frame (sheet 2 of 3).

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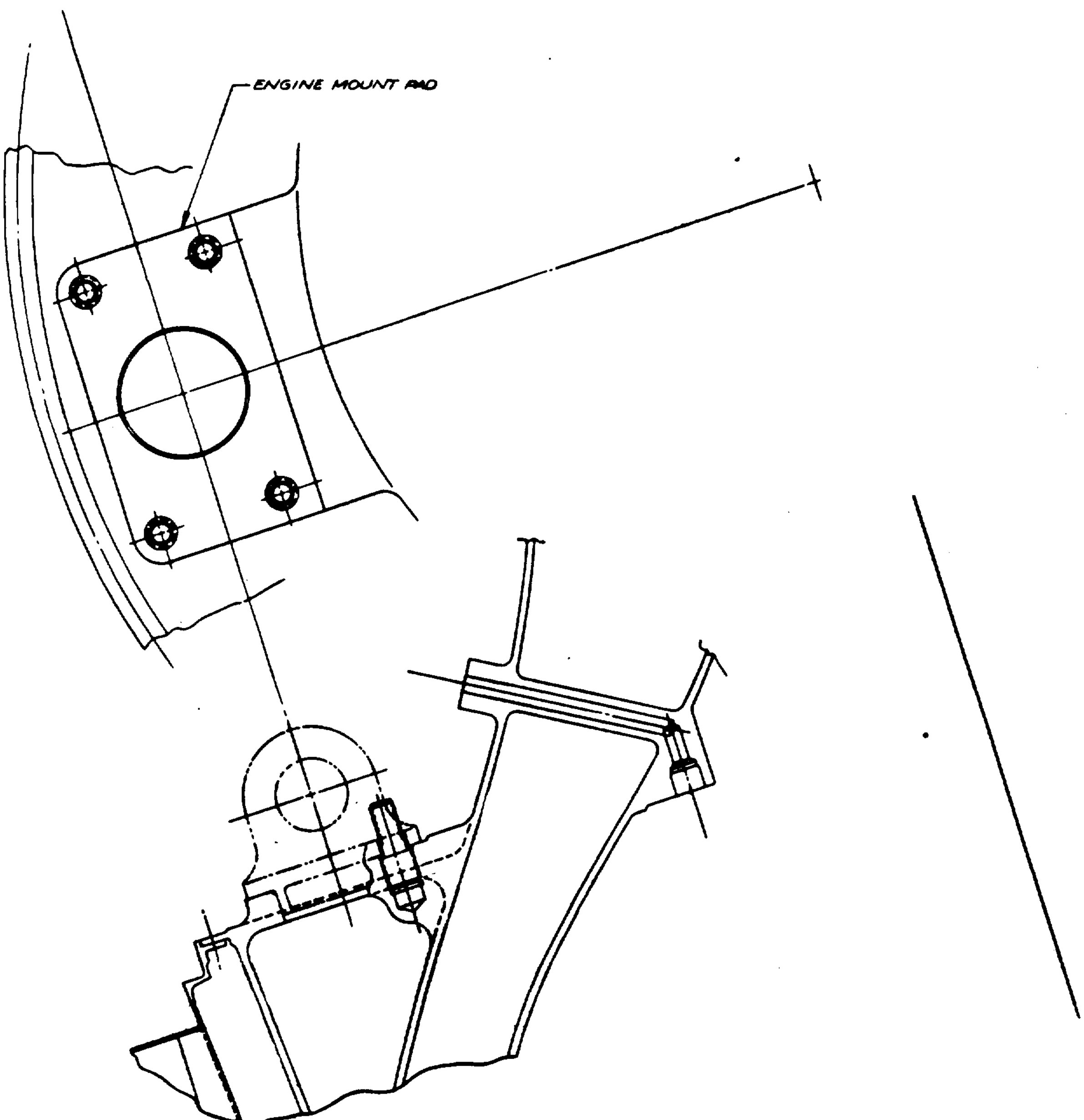
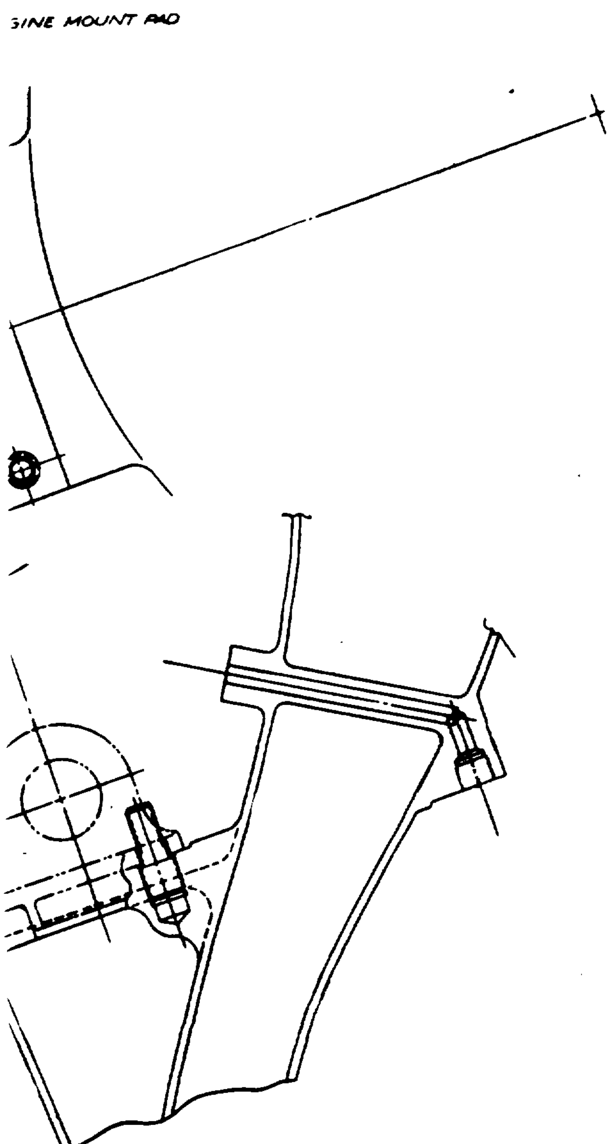
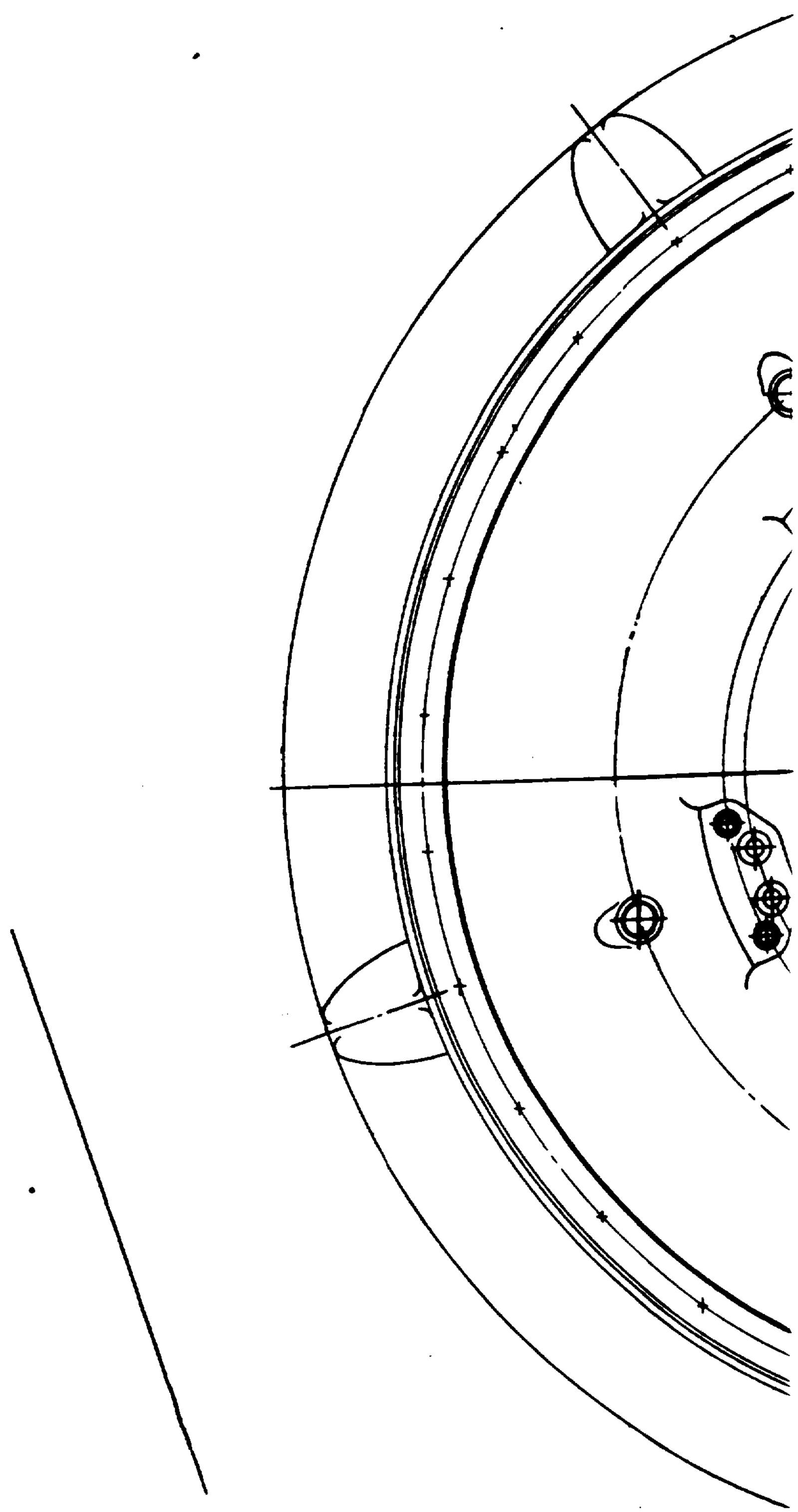


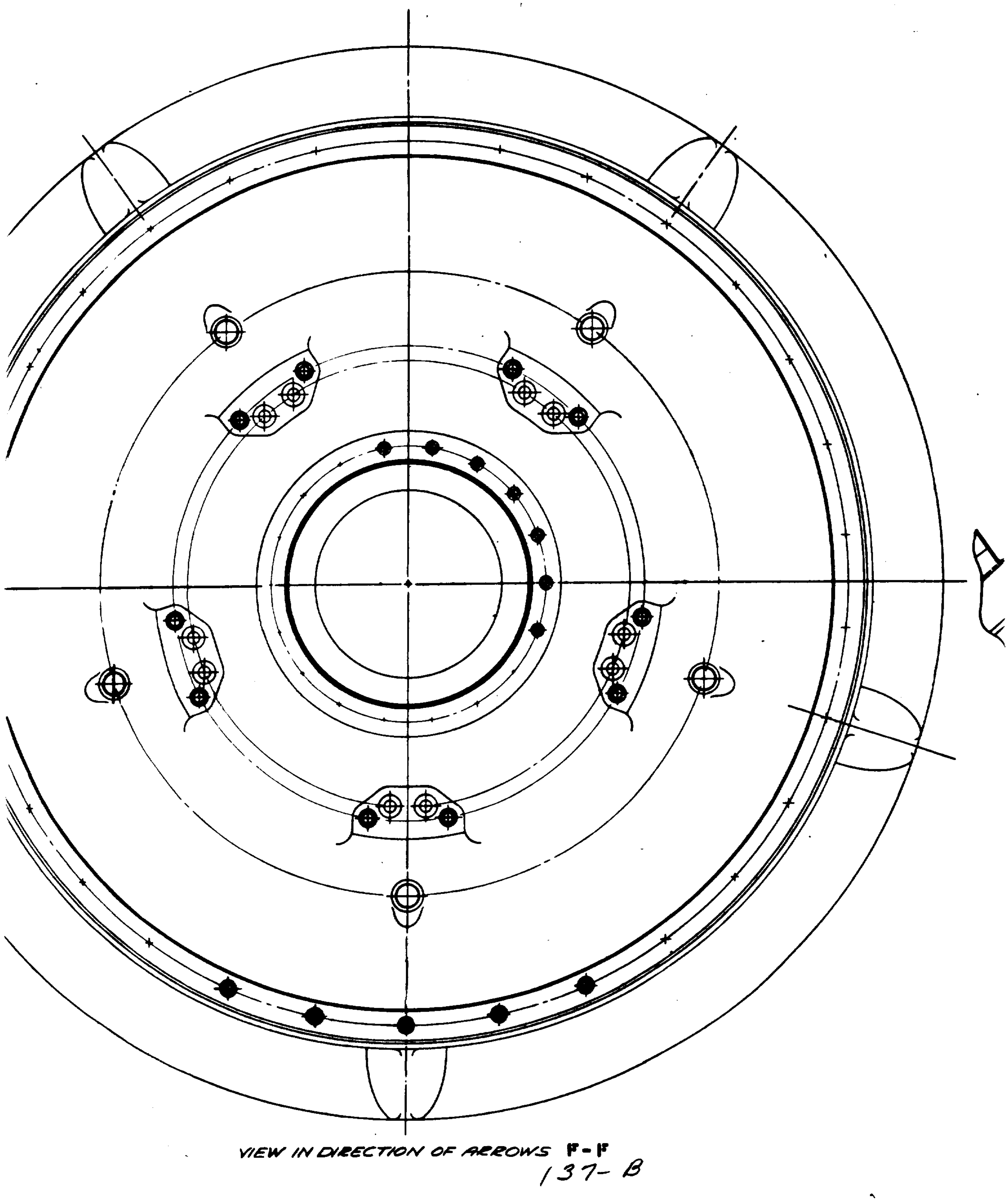
SECTION D - D

137-A



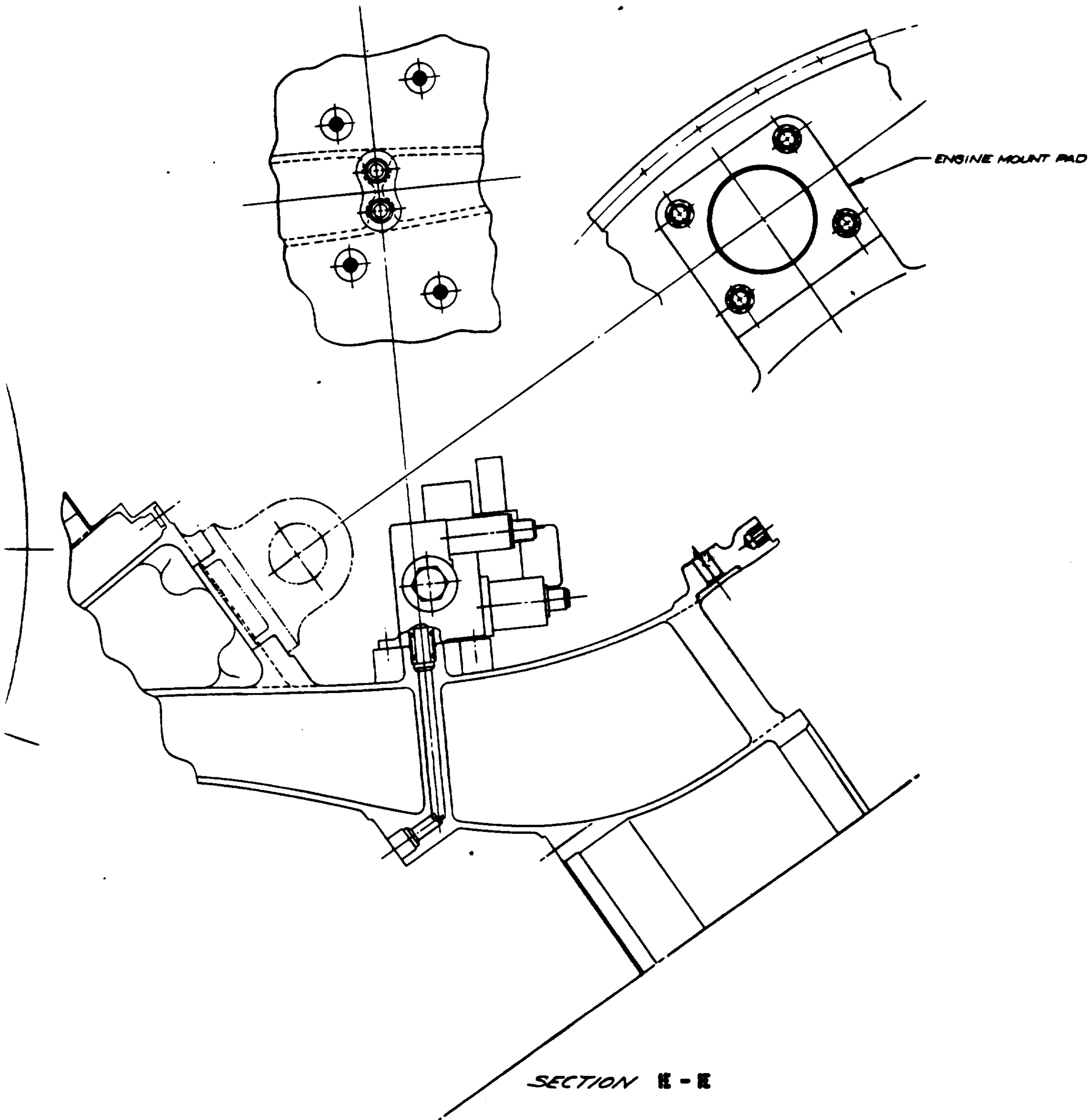
SECTION D - D





VIEW IN DIRECTION OF ARROWS F - F

137- B



9082-73

Figure 70. PD370-25A front frame (sheet 3 of 3).

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pads on its aft side which are used to support the engine assembly as well as the fan bypass duct and engine fairings in either left- or right-hand installations. A third mounting point at the aft end of the engine reacts engine torques and completes the three-point mounting arrangement.

The inner and outer walls of this assembly form the flow path contours for the transition duct between the fan exit and the compressor inlet. A flange at the exit of this transition provides the attachment point for the core engine assembly. The interior of the casting provides a housing for the fan reduction gearing and the cross shafting gearset as well as a mounting base for the fan and engine rotor main bearings. On the outside diameter of the casting, flanges are provided at each end of a stiff, three-sided box member for attaching the fan bypass duct assembly. The rear radial panel of this box structure is the surface on which the engine mounting pads as well as mounting pads for the two Beta regulators are located. Loads are transmitted across the inner flow path by five struts which are an integral part of the casting. These hollow struts provide access routes for lubrication system lines and the cross drive quill shaft.

The fan bypass duct which mounts on the OD of the front frame is a fabricated aluminum weldment. It consists of outer and inner flow path assemblies connected by 10 integral struts. The inner flow path assembly includes mounting flanges at the fore and aft ends for attachment to the front frame. The 10 hollow struts are fabricated from aluminum sheet and contoured to form the forward portion of an airfoil shape which is completed by mating struts in the nacelle assembly. Four of these struts are wider than the others; they are located on each side—two 18 degrees below the horizontal center line and two 36 degrees from the top vertical center line. The lower two are required to accommodate the cross drive quill shaft for either left- or right-hand installation. These struts also serve to mask the lower aircraft mounting links which penetrate the nacelle at this circumferential location. The upper pair of wide struts mask the upper left or right mounting links, which also coincide with the strut circumferential locations, to reduce aerodynamic blockage to a minimum.

The outer flow path portion of this assembly extends forward from the strut leading edges to a point just ahead of the fan blade tips, where a flange is provided for attachment of the inlet bellmouth. This portion of the duct is reinforced with an aluminum honeycomb structure to provide the required stiffness with a minimum of weight. Outboard of the fan blade tips, a recess in the fan shroud is filled with an abradable compound to minimize the effect of blade tip rubs. This material can easily be replaced—if, for example, a high g-load landing were to cause an inadvertent blade tip rub. An additional circumferential stiffening rib has been added just forward of the strut leading edges. This flange also provides a mounting base for a saddle-type bearing housing bracket which extends from this flange aft to the rear duct flange. This bearing housing supports the outer end of the cross drive quill shaft, which also contains an internal spline for continuation of the cross drive shafting.

pads on its aft side which are used to support the engine assembly as well as the fan bypass duct and engine fairings in either left- or right-hand installations. A third mounting point at the aft end of the engine reacts engine torques and completes the three-point mounting arrangement.

The inner and outer walls of this assembly form the flow path contours for the transition duct between the fan exit and the compressor inlet. A flange at the exit of this transition provides the attachment point for the core engine assembly. The interior of the casting provides a housing for the fan reduction gearing and the cross shafting gearset as well as a mounting base for the fan and engine rotor main bearings. On the outside diameter of the casting, flanges are provided at each end of a stiff, three-sided box member for attaching the fan bypass duct assembly. The rear radial panel of this box structure is the surface on which the engine mounting pads as well as mounting pads for the two Beta regulators are located. Loads are transmitted across the inner flow path by five struts which are an integral part of the casting. These hollow struts provide access routes for lubrication system lines and the cross drive quill shaft.

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Inboard of the flowpath at the forward edge of the cast inner housing is a bolt circle by which the fan bearing housing is attached to the frame. These bolts also attach the OGV assembly, which consists of the fan exit splitter nose and an inner flowpath connected by 87 outlet guide vanes. These elements are brazed into one integral unit which pivots on the bypass duct inner wall and the transition duct outer wall and mates with a rotating seal member at its forward edge.

All structural members of this assembly were designed to meet or exceed, with a positive margin of safety, the design criteria specified under the "Mechanical Limits" heading of the Design Requirements and Goals section. Stress analyses of the structure were conducted simultaneously with the design effort to ensure the evolution of a workable preliminary design.

LUBE SYSTEM

The lift/cruise gearbox incorporates a complete oil system separate from the power section oil system. This system is shown schematically in Figure 71. A separate oil system is required because the L/C gearbox and fan must be operated when the power section is shut down.

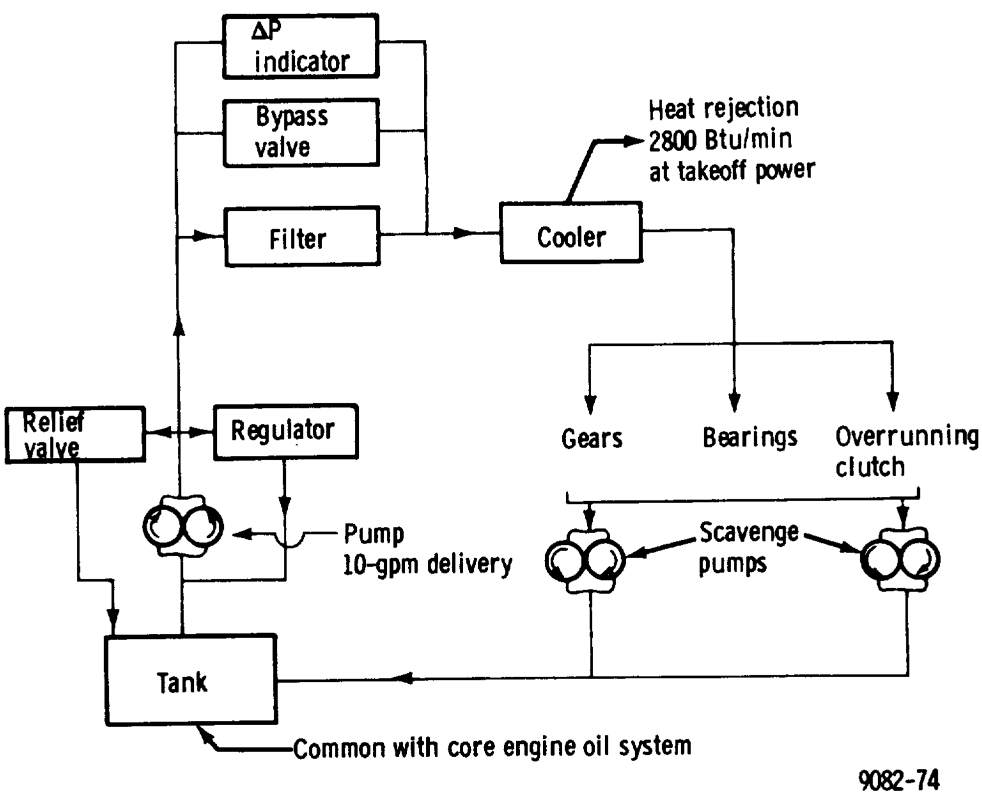


Figure 71. Lift/cruise gearbox oil system schematic.

The only common component for the two oil systems is the oil tank.

The L/C oil pumps are located in the gearbox, driven from the fan shaft as shown in Figure 72. The high-pressure pump and the scavenge pumps are located in this area.

The air-oil cooler is airframer supplied and is not included in the engine weight.

ACCESSORIES

The mechanically driven accessories are mounted on the HP-driven gearbox located between the primary and secondary flow path (see Figure 72). The gearbox is attached directly to the fan support structure. The following airframe and engine accessories are located on the gearbox:

- Centrifugal breather
- Permanent magnet generator
- Oil pumps (for power section)
- Starter (airframe accessory)
- Hydraulic pump (airframe accessory)
- Fuel control and pump
- Alternator (airframe accessory—may be driven through CSD)

The pertinent gearbox speeds, gear geometry, powers, and design stress levels are listed in Table XLI.

WEIGHTS

The estimated weight breakdown for the PD370-25A engine is summarized in Table XLII. The calculation of the weights for new parts was coordinated with the design and stress groups to ensure proper element cross section thicknesses, etc, as the stress analysis and design progressed. The fan inlet, fan shaft and internal support, cross drive, and planet system weights were estimated from available detail sketches. A total of 74 lb of the planetary gearing system is directly traceable to the T56-A-14 engine weights list. The overrunning clutch, with small shafting variations, is directly traceable to the T56-A-18. The compressor inlet vane assembly and its supports are directly traceable to the XT701 engine weights list. All other weights, from the compressor rotor to the rear turbine bearing support, are exact weights from the XT701 weights list. The weights of the fuel, lubrication, electrical, and piping systems and the accessory drive gearbox are very similar to the XT701 system weights. This results in 1165 lb of well defined parts, or almost 50% of the total weight of the PD370-25A engine.

TABLE XLI. PD370-25 ACCESSORY GEAR TRAIN SUMMARY

Description	Geometry				Normal operation							Starter static proof		
	N	D.P.	Pitch dia (in.)	Face width (in.)	RPM	HP	PLV (ft/min)	Bending stress-(psi)	Crushing stress-(psi)	Separating force (lb)	Tangential force (lb)	Max torque (ft/lb)	Bending stress (psi)	Crushing stress (psi)
Engine bevel gear	43	8.775	4.9000	0.400	15,049	157.5	15,709	18,456	136,193	81	353	149	40,741	202,347
Engine bevel pinion	35	8.775	3.9870	0.400	18,489	157.5	15,709	17,328	136,193	99	353	121	38,179	202,347
Gearbox bevel pinion	19	8.20	2.3170	0.625	18,489	157.5	11,210	14,545	142,956	-248	515	121	39,337	235,097
Gearbox bevel gear	47	8.20	5.7320	0.625	7,474	157.5	11,210	15,576	142,956	347	515	300	42,224	235,097
Starter driven gear	35	10	3.5000	0.443	7,474	47.6	6,826	26,342	160,000	331	710	300	45,000	227,490
Starter gear	35	10	3.5000	0.340	7,474	-----	6,826	34,322	160,000	331	710	300	46,127	227,490
Hydraulic pump gear	52	10	5.2000	0.404	5,030	75.0	6,826	24,152	160,000	331	710	---	------	-------
F/C-F/P drive gear	52	10	5.2000	0.218	5,030	-----	6,826	21,892	160,000	162	348	---	------	-------
F/C-F/P gear	35	10	3.5000	0.239	7,474	32.0	6,826	21,892	160,000	162	348	---	------	-------
Alternator drive gear	52	10	5.2000	0.150	5,030	-----	6,826	17,689	151,774	90	193	---	------	-------
Alternator gear	33	10	3.3000	0.159	7,926	40.0	6,826	18,682	154,514	90	193	---	------	-------
Oil pump drive gear	52	10	5.2000	0.150	5,030	-----	6,826	4,643	77,761	24	50	---	------	-------
Oil pump drive gear	19	10	1.9000	0.223	5,030	-----	2,494	13,559	157,338	65	138	---	------	-------
Oil pump gear	53	10	5.3000	0.150	1,803	5.0	2,494	13,559	157,338	65	138	---	------	-------
PMG/breather drive gear	19	10	1.9000	0.150	5,030	-----	2,494	10,537	113,873	34	73	---	------	-------
PMG/breather drive gear	61	16	3.8125	0.175	5,030	-----	5,004	5,663	99,910	17	36	---	------	-------
PMG/breather gear	19	16	1.1875	0.180	16,149	5.5	5,004	10,248	99,910	17	36	---	------	-------

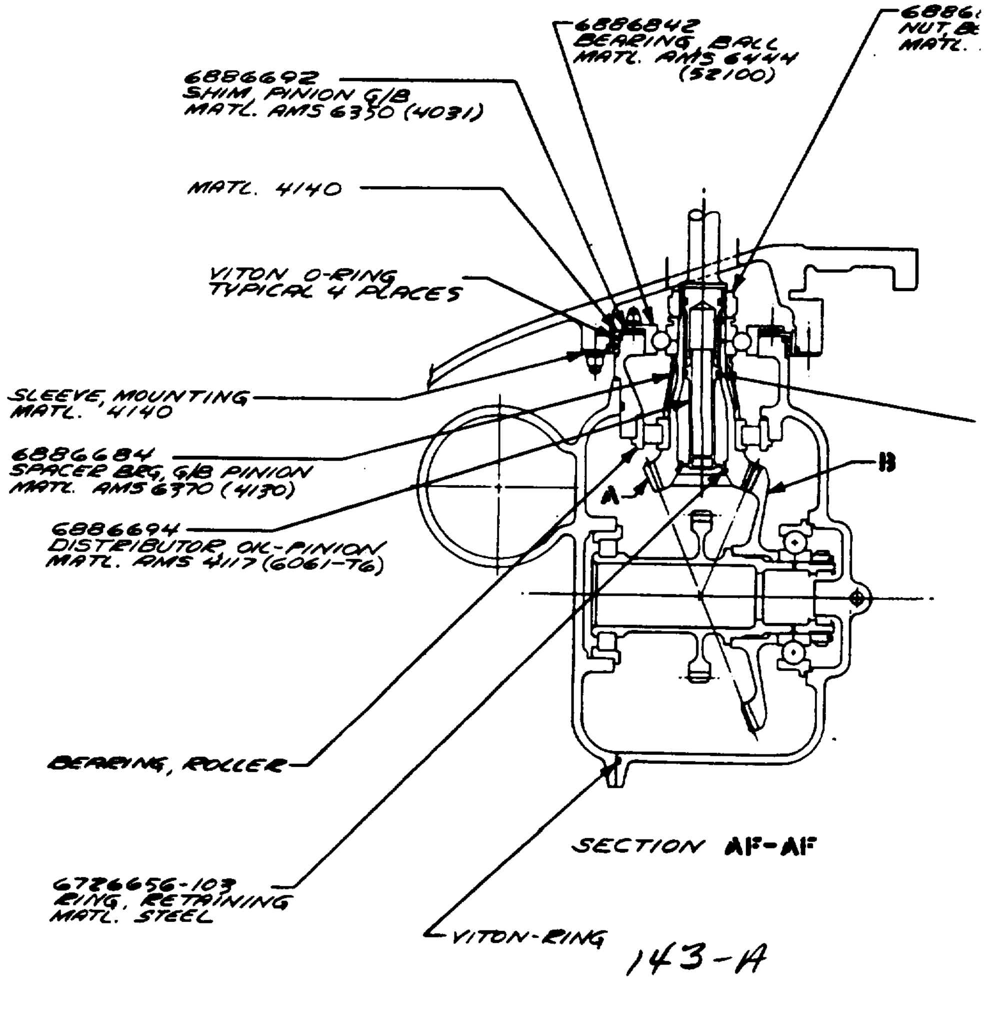
Refer to Appendix B for explanation of symbols.

	GEAR DESCRIPTION	DIRECTION OF ROTATION	GEAR TYPE	SPEED RPM	GEAR PITCH	NO. OF TEETH
A	GEARBOX BEVEL PINION	CCW	SPIRAL BEVEL	18489	8.2	19
B	GEARBOX BEVEL GEAR	CCW	SPIRAL BEVEL	7474	8.2	47
C	STARTER DRIVEN GEAR	CCW	SPUR	7474	10	35
D	STARTER GEAR	CW	SPUR	7474	10	35
E	OIL PUMP DRIVE GEAR	CCW	SPUR	5030	10	52
F	OIL PUMP DRIVE GEAR	CCW	SPUR	5030	10	19
G	OIL PUMP GEAR	CW	SPUR	1803	10	53
H	PMG/BREATHER DRIVE GEAR	CCW	SPUR	5030	10	19
J	PMG/BREATHER DRIVE GEAR	CCW	SPUR	5030	16	61
K	PMG/BREATHER GEAR	CW	SPUR	16149	16	19
L	HYDRAULIC PUMP GEAR	CW	SPUR	5030	10	52
M	F/C AND F/P DRIVE GEAR	CCW	SPUR	5030	10	52
N	F/C AND F/P GEAR	CW	SPUR	7474	10	35
P	ALTERNATOR DRIVE GEAR	CCW	SPUR	5030	10	52
R	ALTERNATOR GEAR	CW	SPUR	7926	10	33

BEARINGS MARKED AD - OUTER RACE 6860486
RETAINER 6860487
ROLLER 6860488

BEARINGS MARKED AE - OUTER RACE 6860489
RETAINER 6860490
ROLLER 6860491

DIRECTION OF ROTATION IS VIEWED FROM THE AFT POSITION LOOKING FORWARD



SECTION AF-AF

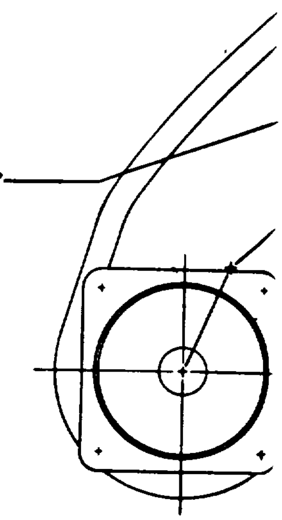
...PTION	DIRECTION OF ROTATION	GEAR TYPE	SPEED RPM	GEAR PITCH	NO. OF TEETH	PRESS. ANGLE	PITCH DIAMETER	SPIRAL ANGLE
...L PINION	CCW	SPIRAL BEVEL	18489	8.2	19	25°	2.3170	35°
...L GEAR	CCW	SPIRAL BEVEL	7474	8.2	47	25°	5.7320	35°
...N GEAR	CCW	SPUR	7474	10	35	25°	3.5000	
...R	CW	SPUR	7474	10	35	25°	3.5000	
...E GEAR	CCW	SPUR	5030	10	52	25°	5.2000	
GEAR	CCW	SPUR	5030	10	19	25°	1.9000	
	CW	SPUR	1803	10	53	25°	5.3000	
DRIVE GEAR	CCW	SPUR	5030	10	19	25°	1.9000	
DRIVE GEAR	CCW	SPUR	5030	16	61	25°	3.8125	
... GEAR	CW	SPUR	16149	16	19	25°	1.1875	
...AP GEAR	CW	SPUR	5030	10	52	25°	5.2000	
...VE GEAR	CCW	SPUR	5030	10	52	25°	5.2000	
...AR	CW	SPUR	7474	10	35	25°	3.5000	
...IVE GEAR	CCW	SPUR	5030	10	52	25°	5.2000	
...EAR	CW	SPUR	7926	10	33	25°	3.3000	

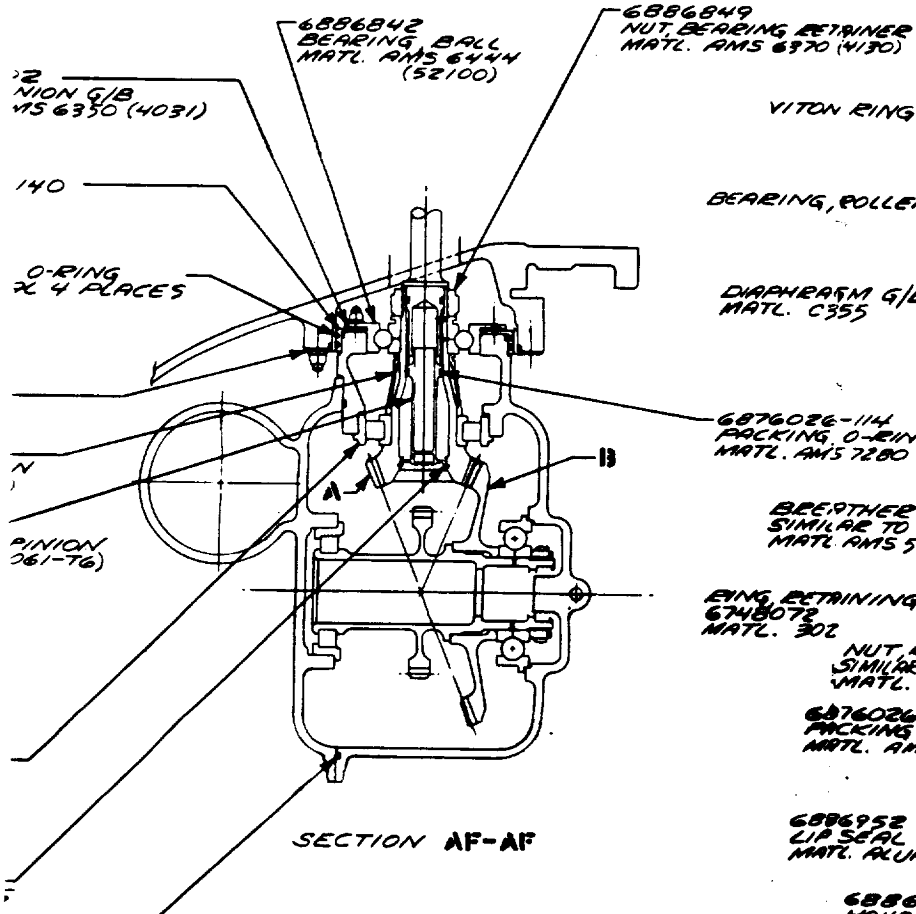
...ED **AD** - OUTER RACE 6860486
RETAINER 6860487
ROLLER 6860488

...ED **AE** - OUTER RACE 6860489
RETAINER 6860490
ROLLER 6860491

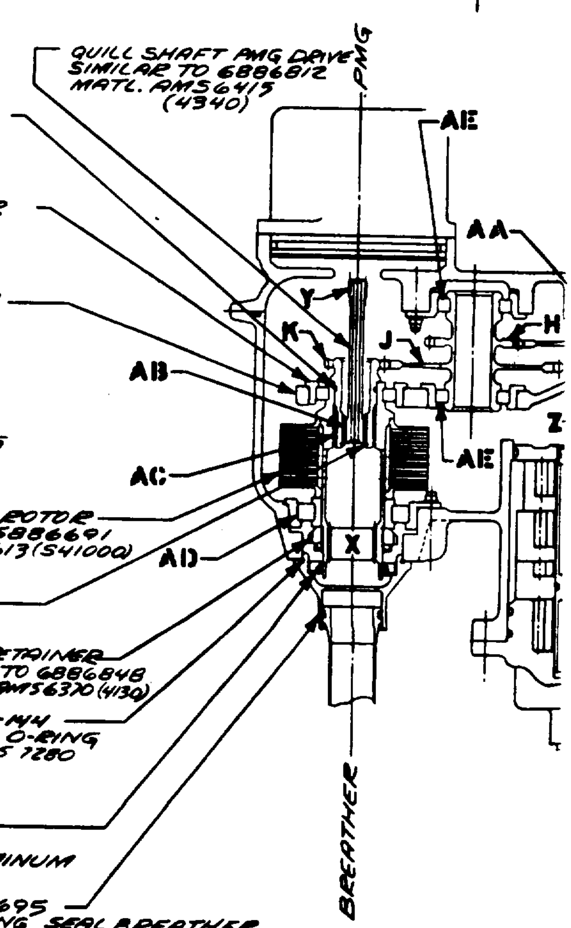
...TION IS VIEWED FROM
...OOKING FORWARD

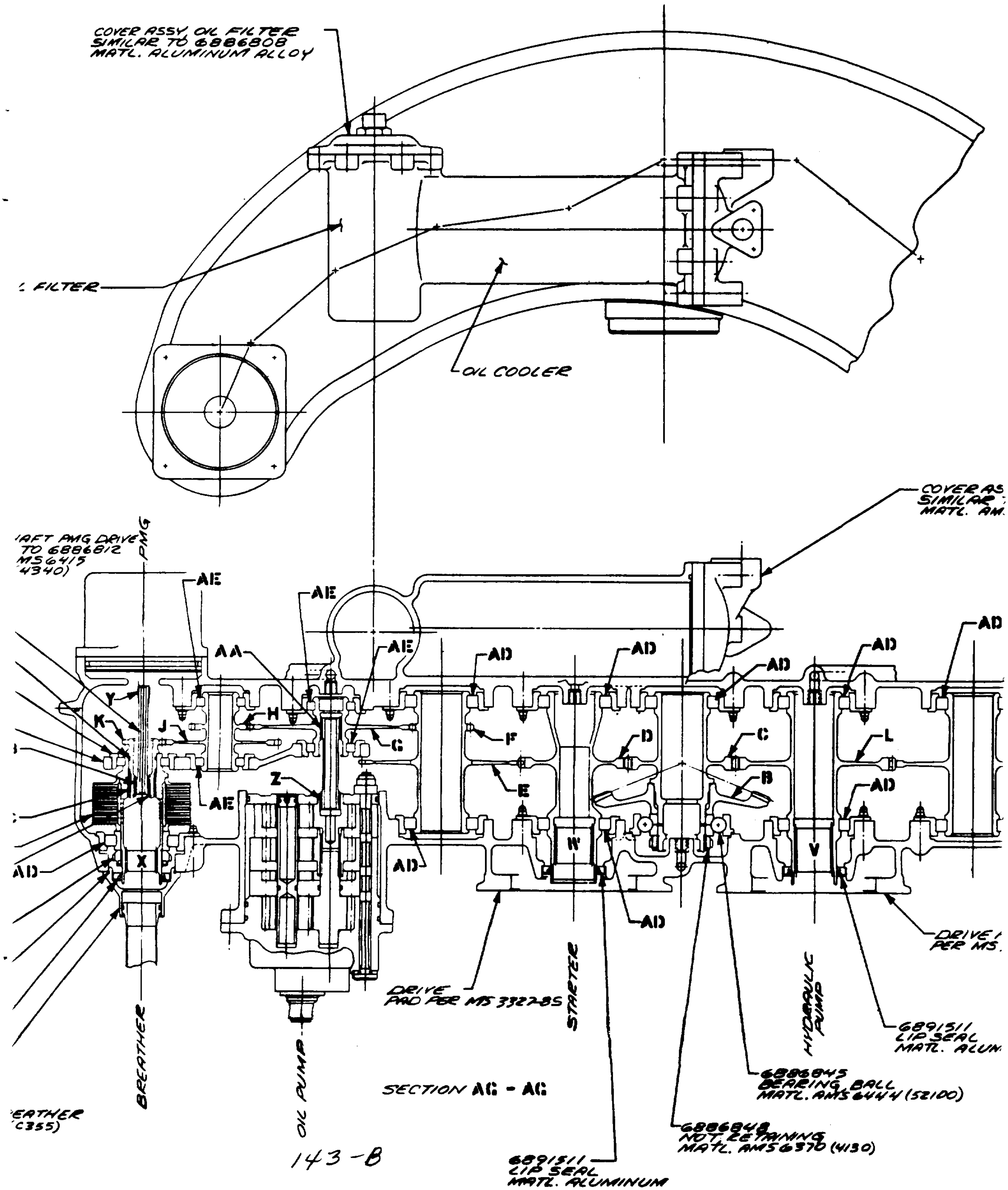
COVER ASSY, OIL FILTE...
SIMILAR TO 688680...
MATL. ALUMINUM AL...





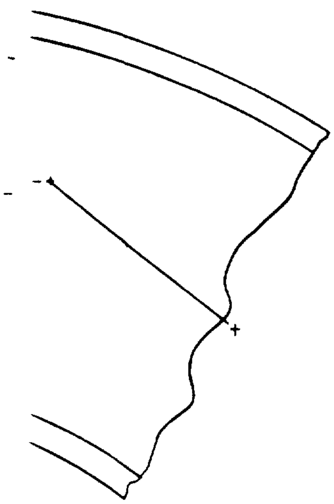
SECTION **AF-AF**



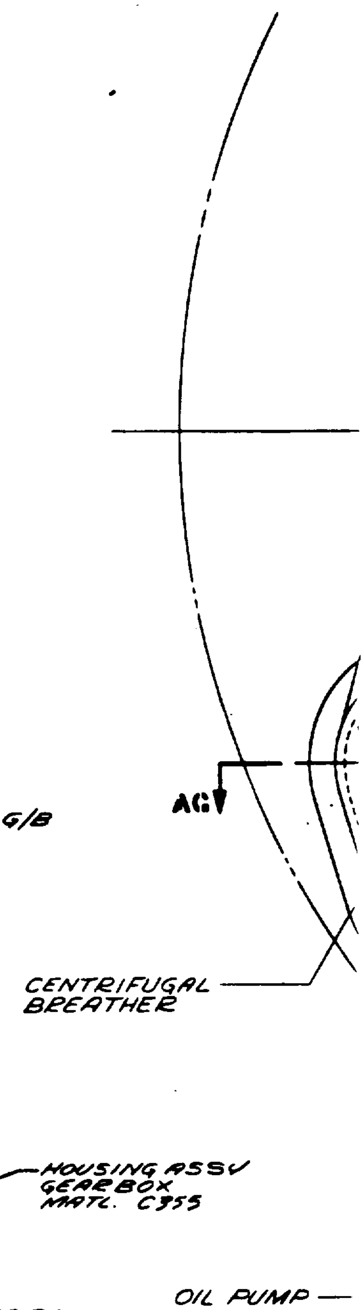


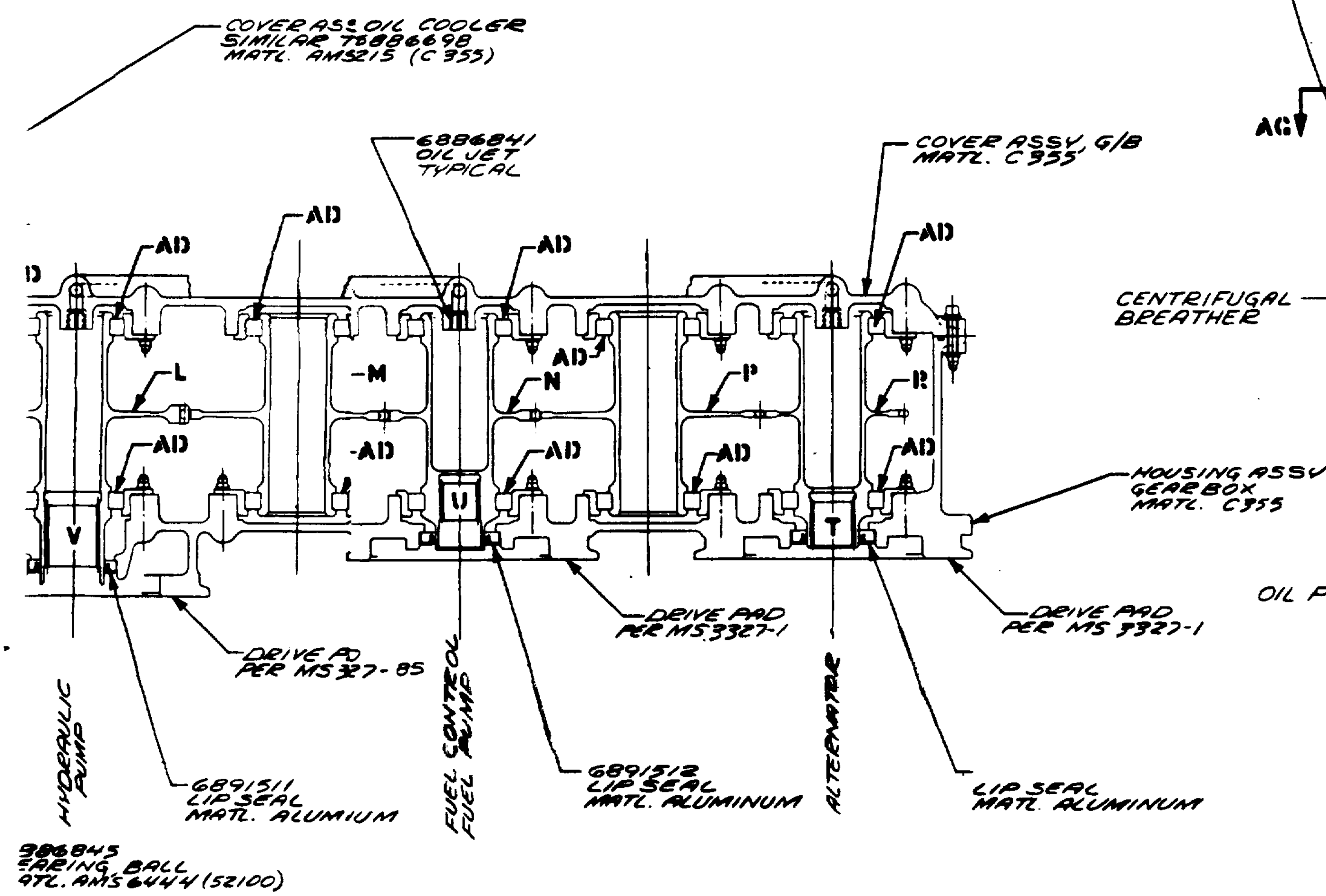
COVER ASSY OIL FILTER
SIMILAR TO 6886808
MATL. ALUMINUM ALLOY
FILTER
OIL COOLER
COVER AS
SIMILAR
MATL. AM
AFT PMG DRIVE
TO 6886812
MS6415
4340)
PMG
AE
AA
AD
Y
K
J
H
G
F
D
C
L
Z
E
B
X
W
V
DRIVE PAD PER MS 3327-8S
STARTER
HYDRAULIC PUMP
DRIVE
PER MS
6891511
LIP SEAL
MATL. ALUM
6886845
BEARING, BALL
MATL. AMS 6444 (52100)
6886848
NUT, RETAINING
MATL. AMS 6370 (4130)
6891511
LIP SEAL
MATL. ALUMINUM
BREATHER
OIL PUMP
SECTION AG - AG
EATHER
C355)

143-B



SPLINE INFORMATION				
	NO. OF TEETH	PITCH	PRESS ANGLE	PITCH DIAMETER
T	16	20/30	30°	.8000
U	16	20/40	30°	.8000
V	24	20/40	30°	1.2000
W	24	20/40	30°	1.2000
X	32	32/64	30°	1.0000
Y	17	48/96	30°	.354167
Z	19	32/64	30°	.59375
AA	19	32/64	30°	.59375
AB	14	32/64	30°	.4375
AC	26	32/64	30°	.8125

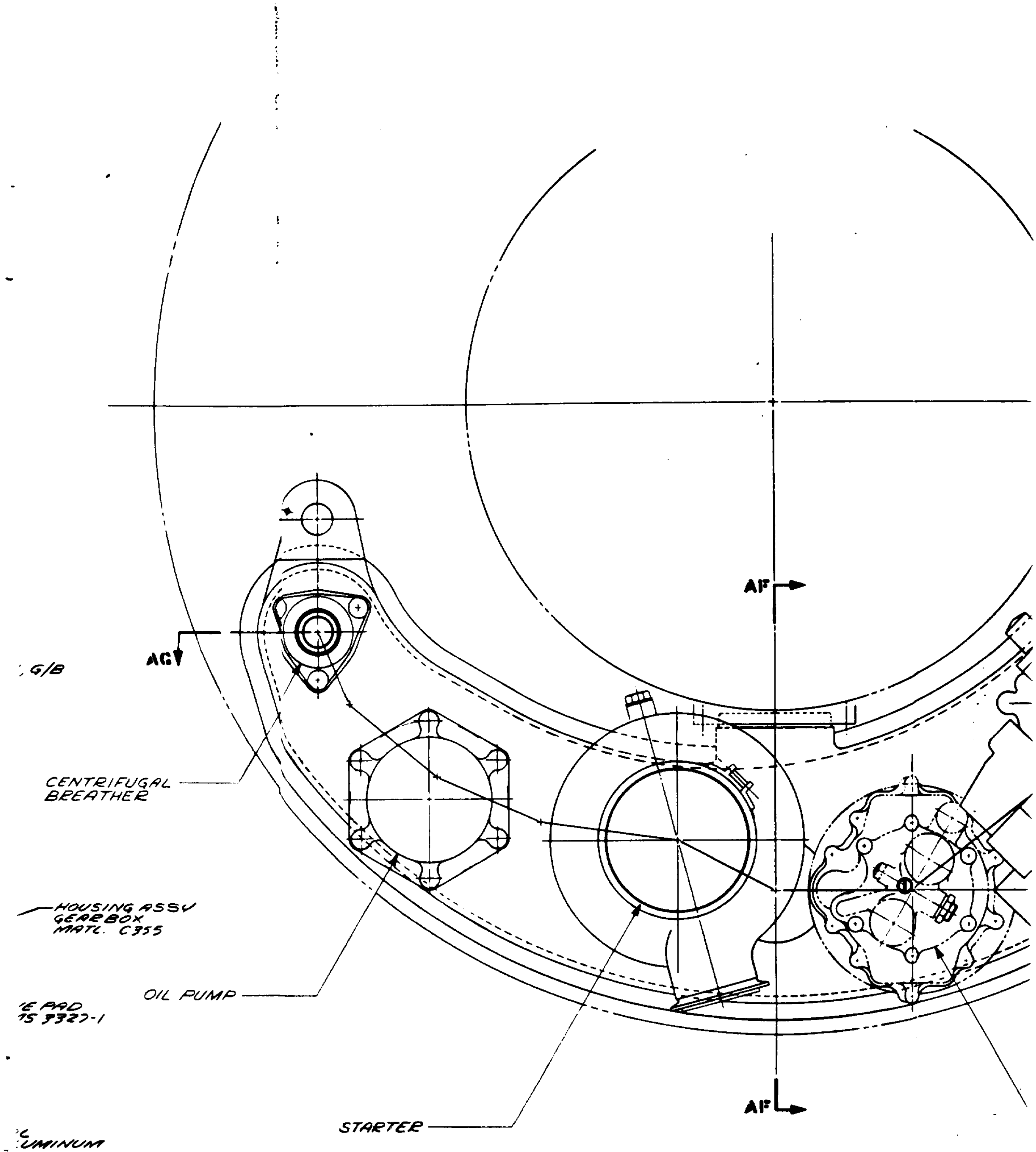




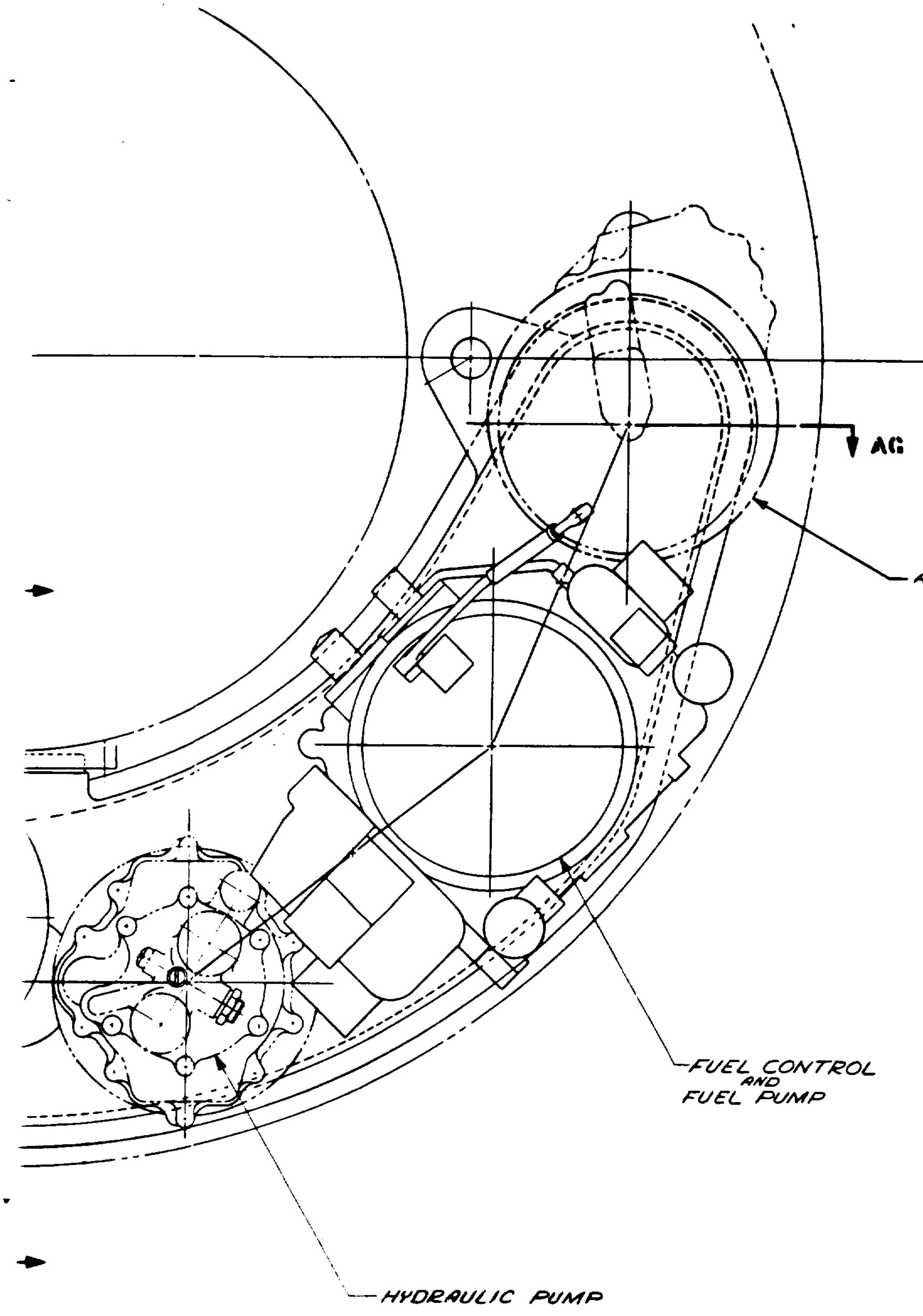
386845
EARING BALL
ATL. AMS 6444 (52100)

NING
-6370 (4130)

143-C



AF
AG
, G/B
CENTRIFUGAL
BREATHER
HOUSING ASSY
GEARBOX
MATL. C355
OIL PUMP
E PAD
S 3327-1
STARTER
UMINUM



9082-75

ALL GEARSHAFT MATERIAL TO BE 9310
ALL FASTNER MATERIAL TO BE A 286

Figure 72. PD370-25A and -25E accessory gearbox.

E

TABLE XLII. PD370-25A WEIGHT AND CG

Reference sketch: Figure 65
Cross drive shaft relation to planet system: Forward
Mount type: Compressor inlet, fixed nacelle
Longitudinal distance, fan blade ℄ to cross drive ℄: 16.8 inches

Engine section	Estimated weight (lb)	$\bar{X}$ (in.)*
Fan inlet	119	14.1
Fan internal housing—Casting	233	22.9
Fan shaft and internal support	199	13.0
Cross drive system	104	15.0
Planet gear system	162	22.3
Overrunning clutch	19	29.5
Supports and compressor inlet vanes	25	36.9
Fan rotor	299	-0.2
Fan nonrotating parts	14	15.0
Fan control	11	30.0
Compressor rotor	127	53.2
Compressor case	117	48.7
Diffuser/combustor	89	64.7
Turbine rotor, HP	86	77.7
Turbine case, HP	44	76.4
Turbine rotor, LP	125	82.7
Turbine case, LP	99	82.9
Turbine rear bearing support	92	90.2
Fuel system	69	49.9
Lube, electrical, piping systems	197	54.0
Accessory drive gearbox	53	33.0
Total weight (no margin)	2293	38.23
Margin	17	
Total engine weight including margin	2310	

*CG datum plane fan blade center line, aft plus.

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LIFT/CRUISE ENGINE—TILT NACELLE

GENERAL DESCRIPTION

The lift cruise engine as designed for the tilt nacelle application is shown in Figure 73.

The complete system arrangement is the same as that described in the preceding section for the fixed nacelle engine except that the cross shaft is aft of the reduction gear.

GEARING

Reduction Gear Assembly

The reduction gear utilizes the same sun, planet, and ring gear components as those in the fixed nacelle engine.

One difference in the tilt nacelle application is that the reduction gear operates at fan power and not at the engine power level. Therefore, the three-engine-operating design point for normal takeoff is 8085 hp. Stress levels for this power are lower than those encountered for the fixed nacelle reduction gear and, therefore, the reliability for a 500-hour life is quite adequate.

Cross Shaft Gear Assembly

The cross shaft drive for the PD370-25E tilt nacelle engine is shown in the Figure 74.

Power is extracted from a spiral bevel gear operating at power turbine speed. The cross shaft gear-to-pinion ratio is 1.14:1, which results in a cross shaft speed of 13,420 rpm at the design speed point.

The spiral bevel gear geometry and materials are shown in Figure 74. Gear stress levels at operating conditions are as follows:

	Normal takeoff	Max power out	Max power in
Horsepower	606	5,045	6,931
Pinion bending stress, psi	4,110	34,200	47,000
Gear bending stress, psi	4,080	34,000	46,700
Crushing stress, psi	78,200	225,700	264,600

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These stress levels are slightly higher than those for the fixed nacelle cross shaft gears; however, the design is still quite adequate for the 500-hour life requirement of the RTA.

BEARINGS

The only significant difference in the bearing arrangement shown for the PD370-25E as opposed to that of the PD370-25A is that tapered roller bearings are used in the cross shaft drive area. The tapered bearings for this application afford the required capacity in the restricted area available. The highest rotational speed for the tapered bearings is 13,420 rpm on the 90-mm outboard spiral bevel pinion position. This results in a DN level of 1.2×10^6 and is considered reasonable for this application.

The bearing system provides the necessary reliability for the 500-hour system life.

OVERRUNNING CLUTCH

The overrunning clutch for the PD370-25E is shown in Figure 75. Functionally, the operation of this clutch is identical with that described in the preceding section for the PD370-25A.

The following are the coupling geometry and stress levels:

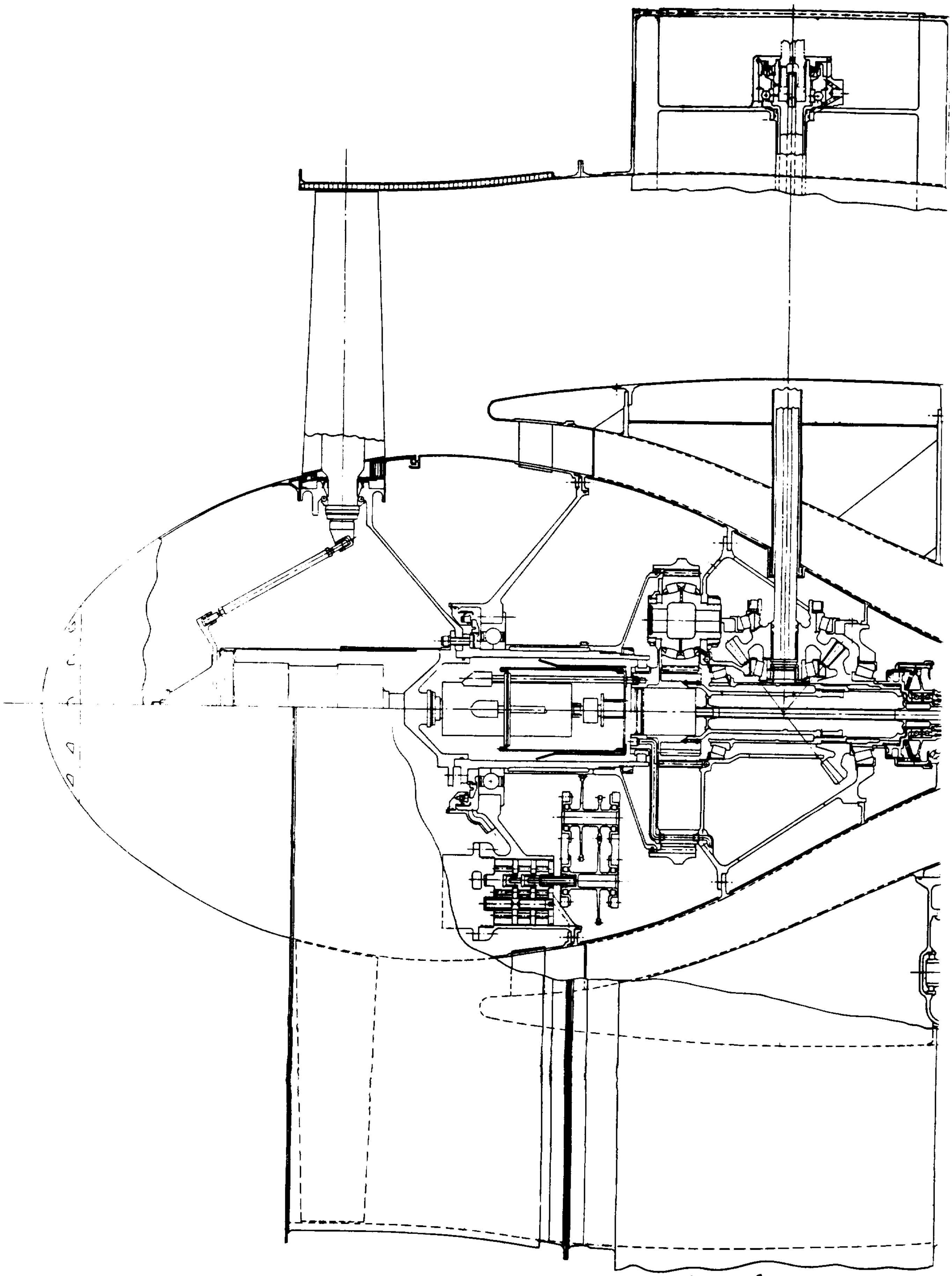
Spline size	8/16
Pitch diameter, in.	5.375
Length, in.	0.3
Torque at max power, in.-lb	48,400
Spline stress at max power, psi	11,200

FAN DRIVE AND INTERFACES

The fan drive and actuator interfaces for the PD370-25E are described in the preceding section and are shown in Figure 69.

STRUCTURE—MOUNTS

The front structural member of the PD370-25E engine configuration is also the mounting base for the tilting nacelle. This structure, the forward frame and bypass duct assembly, are shown in cross section in Figure 75 and in detail in Figure 76. The primary component of this structure is the fan bypass duct assembly. This member attaches directly to the aircraft mounting trunnions and supports the entire engine and nacelle assembly over the full operating regime, from horizontal to vertical. The rear engine mount must also be tied into the monocoque engine outer fairing structure to reduce aft end deflection of the cantilevered engine assembly.



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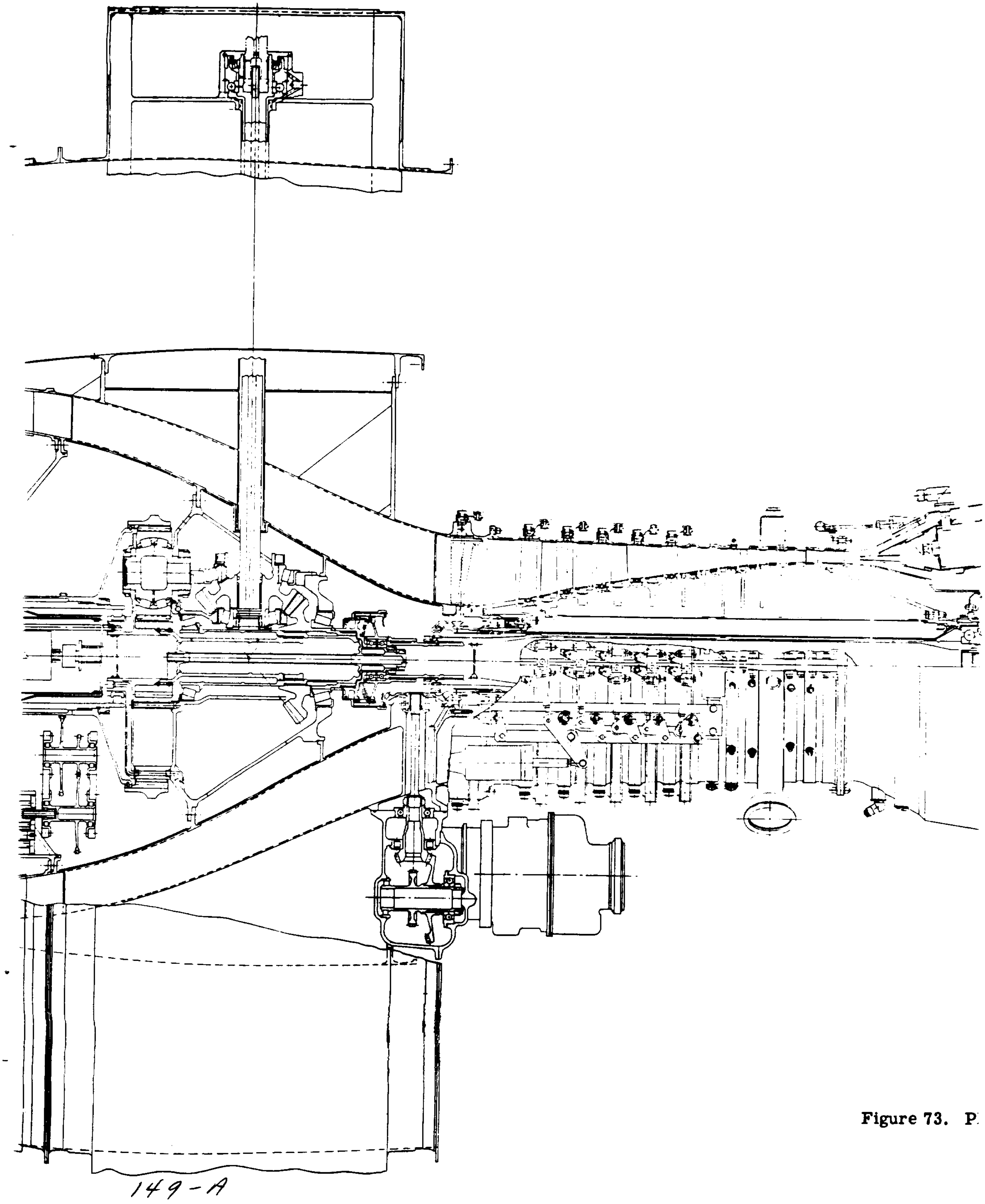


Figure 73. P

149-A

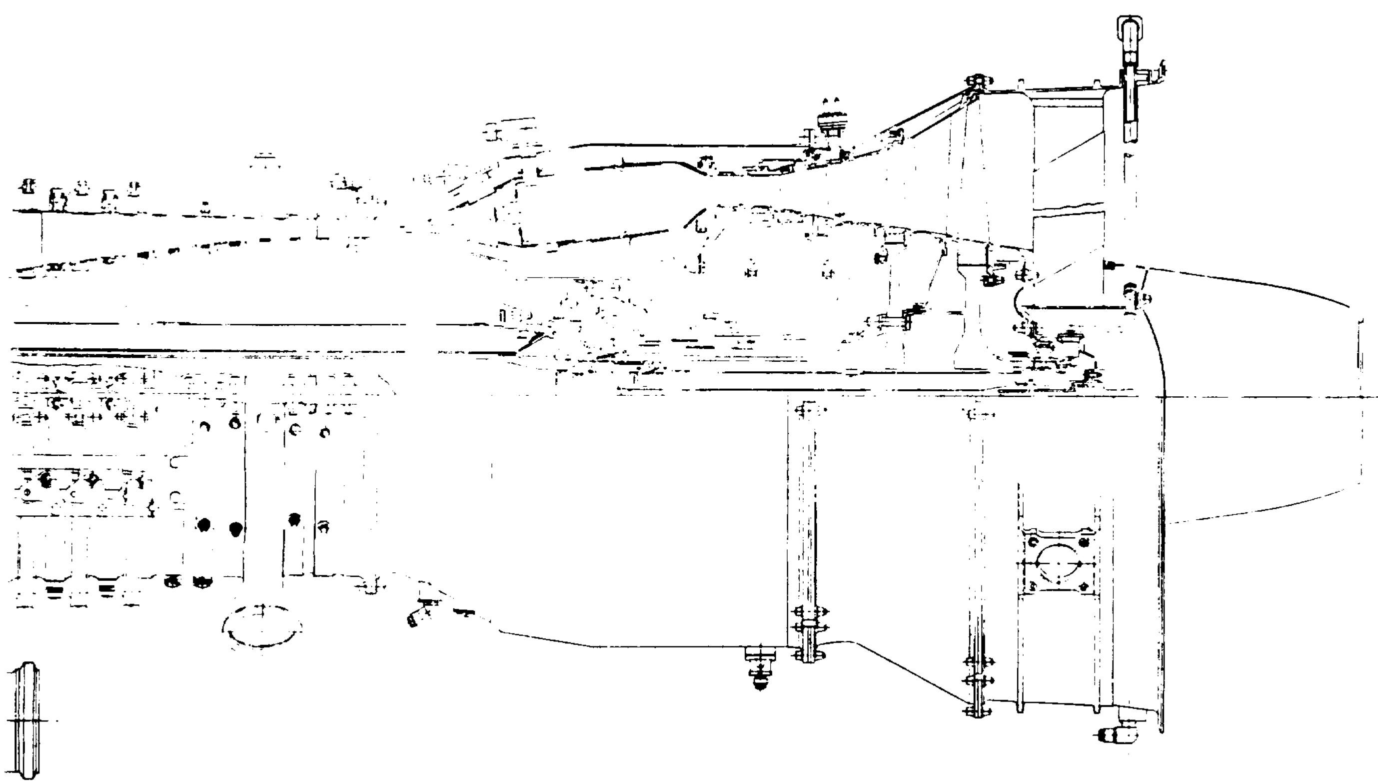
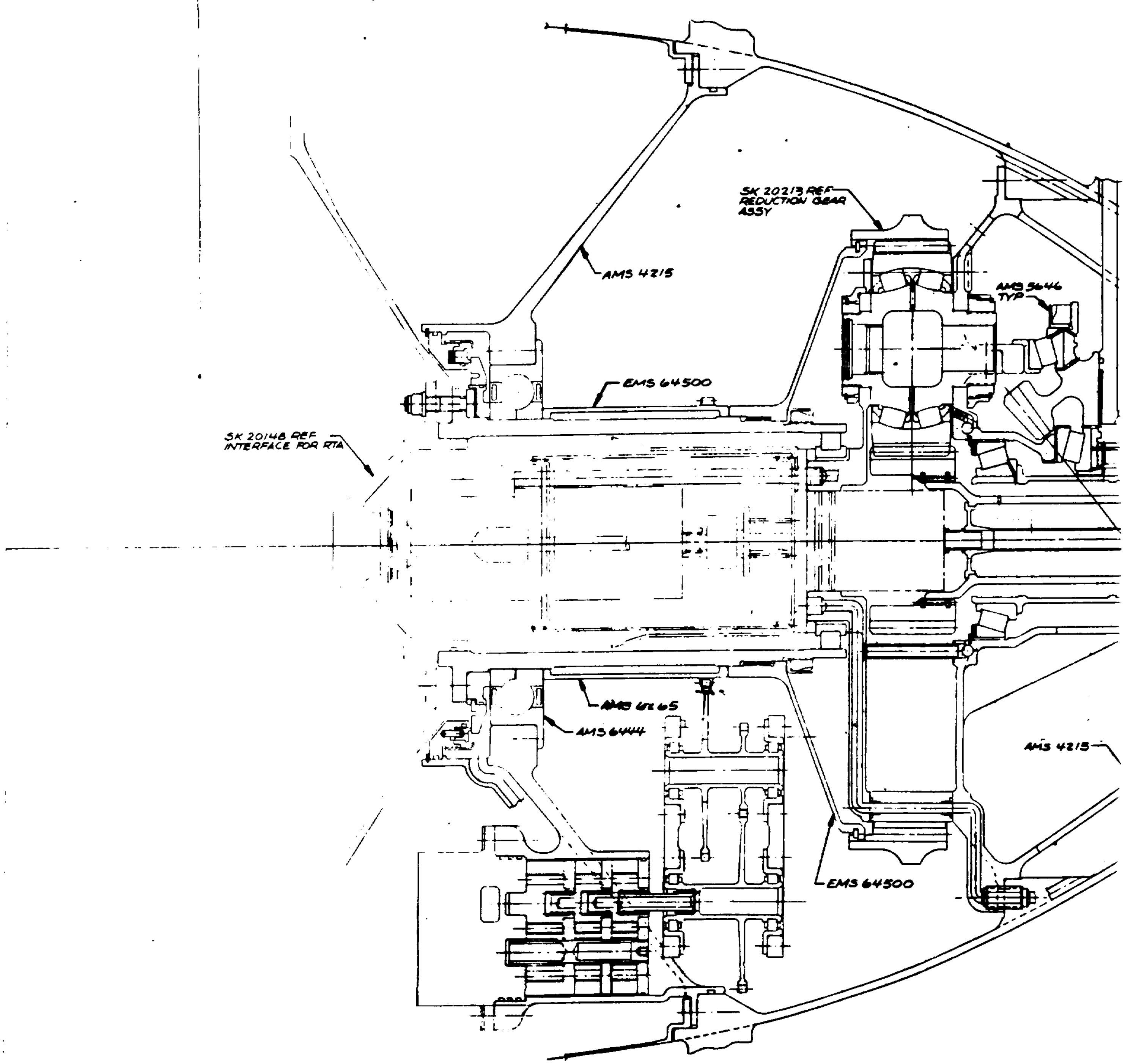
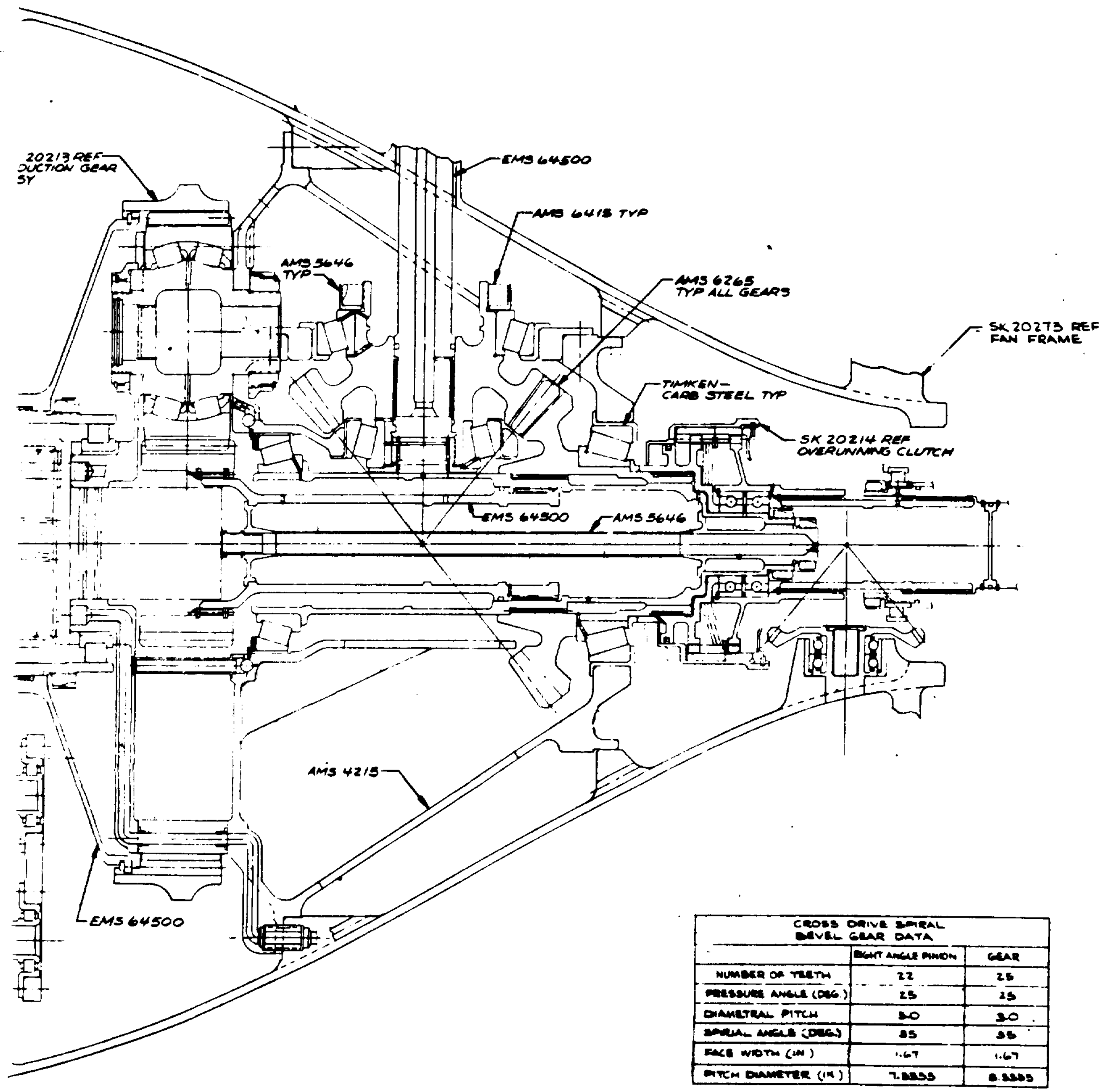


Figure 73. PD370-25E lift/cruise engine.



SK 20213 REF
REDUCTION GEAR
ASSY
AMS 4215
AMS 5646
TYP
EMS 64500
SK 20148 REF
INTERFACE FOR RTA
AMS 6265
AMS 6444
AMS 4215
EMS 64500



CROSS DRIVE SPIRAL BEVEL GEAR DATA		
	RIGHT ANGLE PINION	GEAR
NUMBER OF TEETH	22	25
PRESSURE ANGLE (DEG.)	25	25
DIAMETRAL PITCH	3.0	3.0
SPIRAL ANGLE (DEG.)	35	35
FACE WIDTH (IN)	1.67	1.67
PITCH DIAMETER (IN)	7.3333	8.3333

Figure 74. PD370-25E cross shaft drive.

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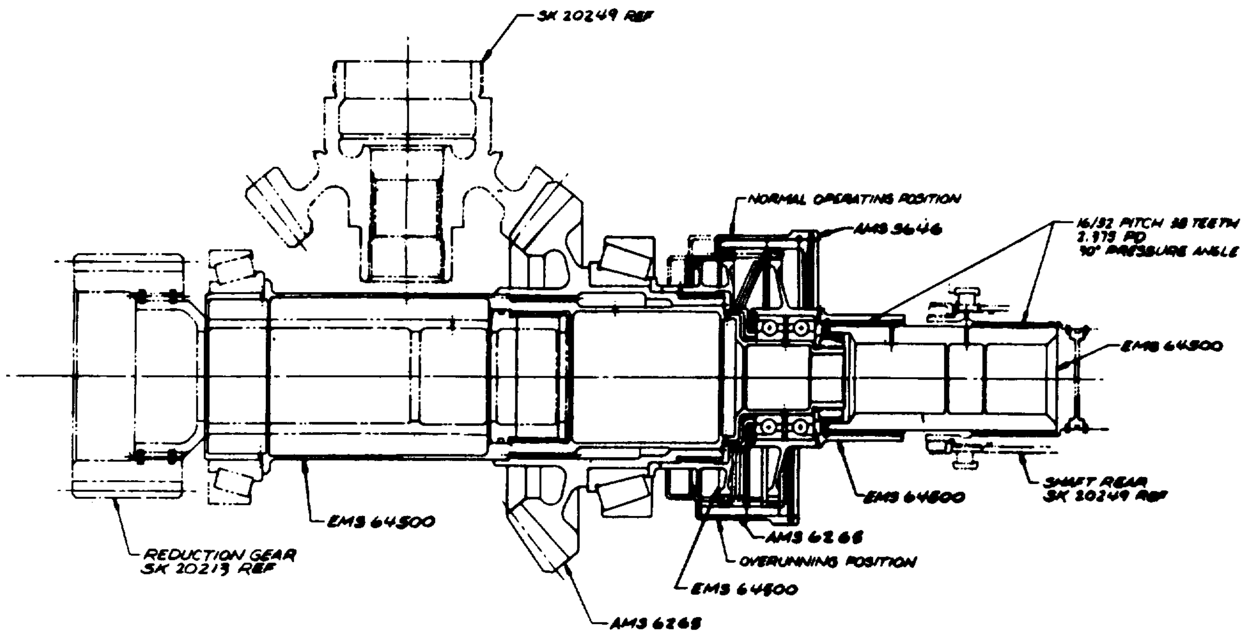


Figure 75. PD370-25E overrunning clutch.

The outer duct assembly consists of an annular box structure, fabricated from sheet and plate 6Al-4V titanium, and includes stiffening ribs, rings, gussets, etc, and, on its horizontal center line, a rigid engine mounting plate complete with a bolt circle and pilot diameter.

This stiff circumferential structure forms the outer flow path contour and is attached to the inner flow path member by a pattern of 10 integral struts. These hollow titanium struts are fabricated from a sheet metal and forging weldment that is contoured to the required aerodynamic shape. They are also ribbed internally to assist in carrying the engine structural loads across the flow path. They penetrate both walls of the outer flow path box structure, where the maximum moments occur, and are welded into place. The struts are also welded into the inner flow path contour assembly to form one rigid integral assembly. The inner and outer duct walls include flanges at their fore and aft faces—the outer duct to provide a mounting base for the inlet bell and nacelle components, and the inner duct for attachment to the engine forward frame. Two of the 10 struts are located on the horizontal center line of the engine, coincident with two of the struts in the inner forward frame assembly, so that the engine crossdrive quill shaft can pass through to the center of the engine mounting pad where it will be unaffected by rotation of the engine nacelle.

The forward frame assembly is also a fabricated titanium structure and consists of inner and outer flow path walls interconnected by six fabricated titanium struts to form the transition duct between the fan exit and the compressor inlet. Two heavy radial plates, which are welded to the flow path walls near the leading and trailing edges of the six struts, are also welded to an interconnecting outer cylindrical wall to form a stiff box structure. Twin gussets at the leading and trailing edges of each strut act to distribute the loads evenly into the box structure and on into the fan bypass duct through the duct mounting flanges. The inner flow path wall assembly includes three internal circumferential flanges which serve as mounting bases for the internal gears and bearings housed in the center of the assembly and stiffen the inner structure further. The flange at the forward edge of the inner wall also serves as the attachment point for the splitter assembly, which consists of the splitter nose and fan duct wall, 87 vanes, and an inner flow path wall—all welded and brazed into one integral assembly. A flange and pilot diameter at the aft end of the transition duct provide the mounting base for the core engine. A series of bosses in the outer wall are provided to mount the variable-inlet-guide vanes for the core engine.

All structural members in this assembly were designed to meet or exceed, with a positive margin of safety, the design criteria specified under the "Mechanical Limits" heading of the Design Requirements and Goals section. Stress analyses of this complex structure were conducted in conjunction with the design effort to ensure that a workable preliminary design evolved.

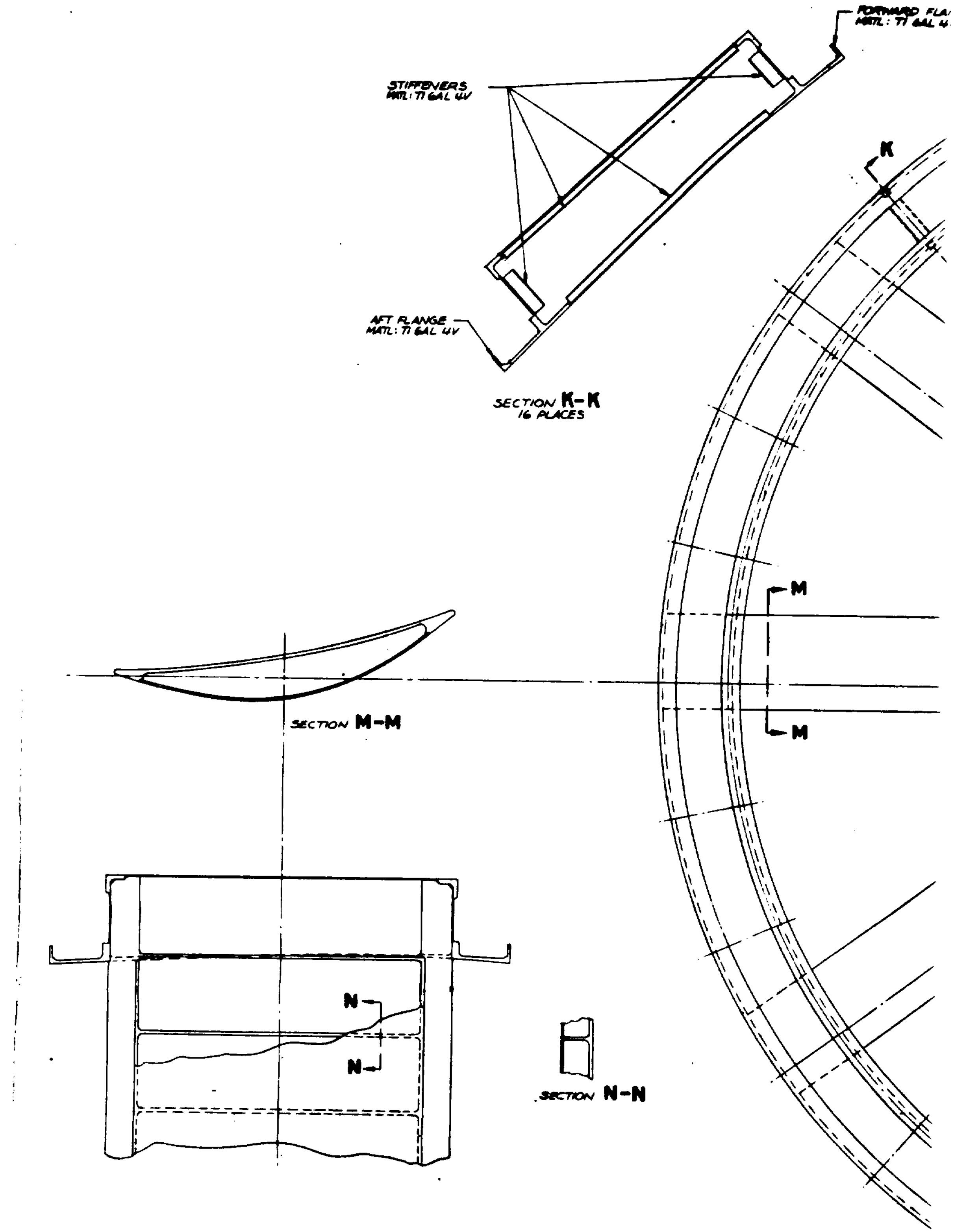
Because the RTA is basically a VTOL aircraft, engine weight is an extremely critical factor, and every effort must be made to reduce the weight of the major components as much as possible. One of the heaviest of these is the outer fan case, which is the major structural member of the engine. The weight of this component, listed in Table XLIII, represents what DDA considers to be the minimum practical weight that can be attained. To achieve this estimated weight, it may be necessary to convert certain detail components of the outer fan duct assembly from the titanium (Figure 76) to a composite structure, such as Borsic fiber/aluminum. A much higher strength-to-density ratio can be achieved by utilizing these advanced structural materials, although the cost would also be considerably higher. The final design of the structure will therefore be the result of trade-off studies among weight, strength, and cost to achieve the optimum combination that meets the objectives of the RTA program.

LUBE SYSTEM

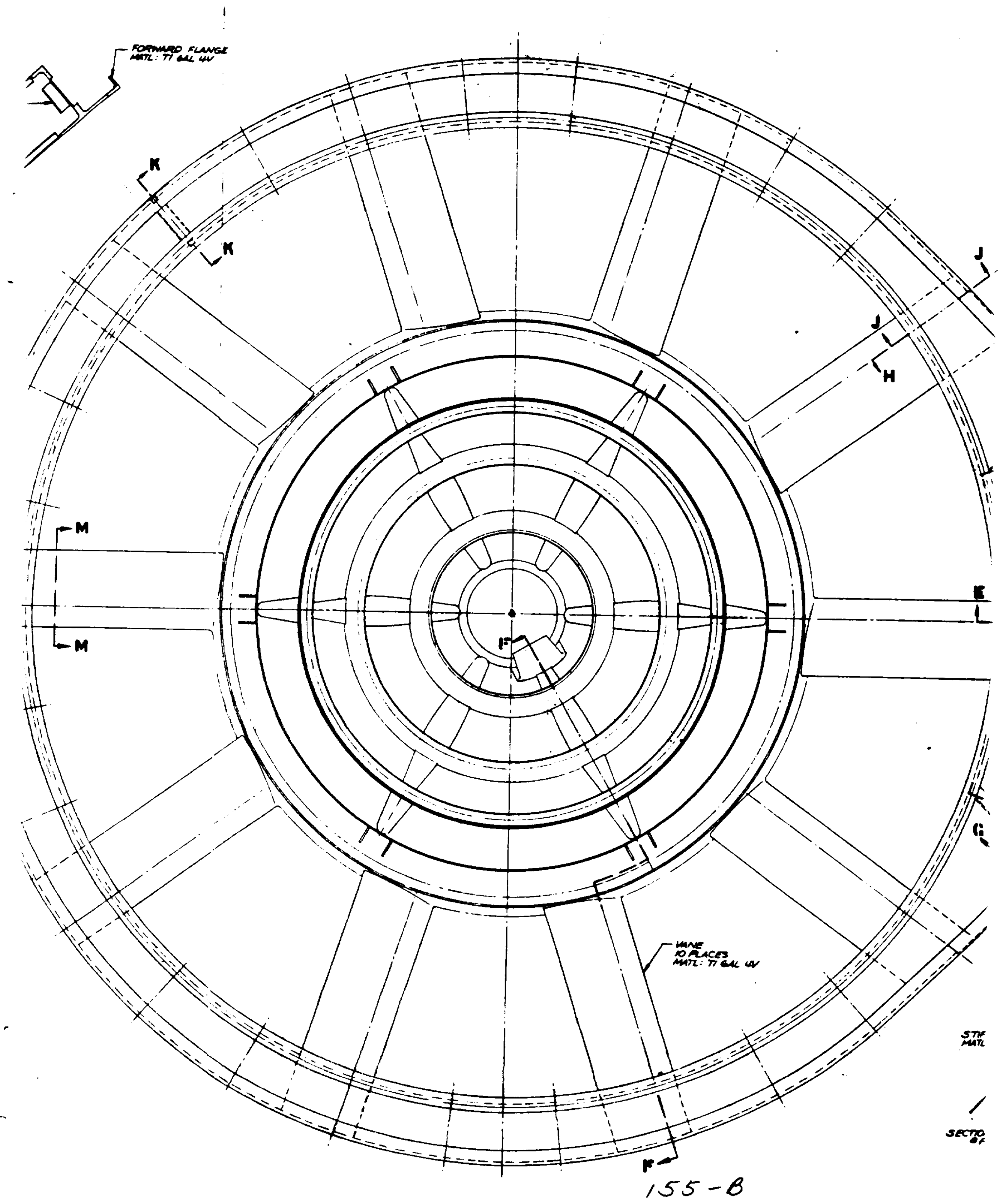
The lube system for the PD370-25E is identical with that described for the PD370-25A in the preceding section.

ACCESSORIES

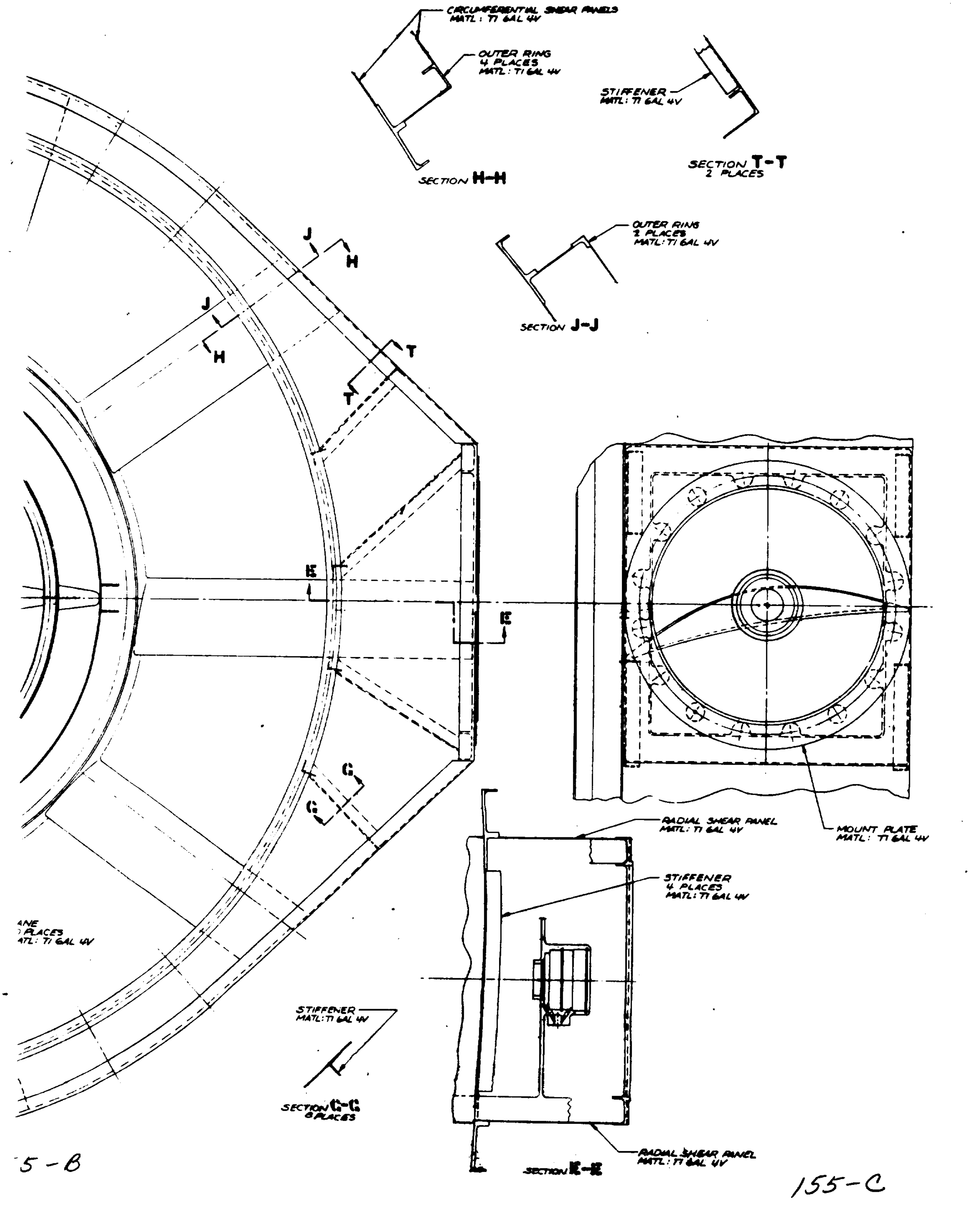
The accessories for the PD370-25E are identical with those described for the PD370-25A in the preceding section.


STIFFENERS
MATL: TI 6AL 4V
AFT FLANGE
MATL: TI 6AL 4V
SECTION K-K
16 PLACES
K
M
M
SECTION M-M
N
N
SECTION N-N

155-A


FORWARD FLANGE
MATL: TI 6AL 4V
K
K
J
J
H
M
M
E
F
G
VANE
10 PLACES
MATL: TI 6AL 4V
STIF
MATL
SECTIO
F

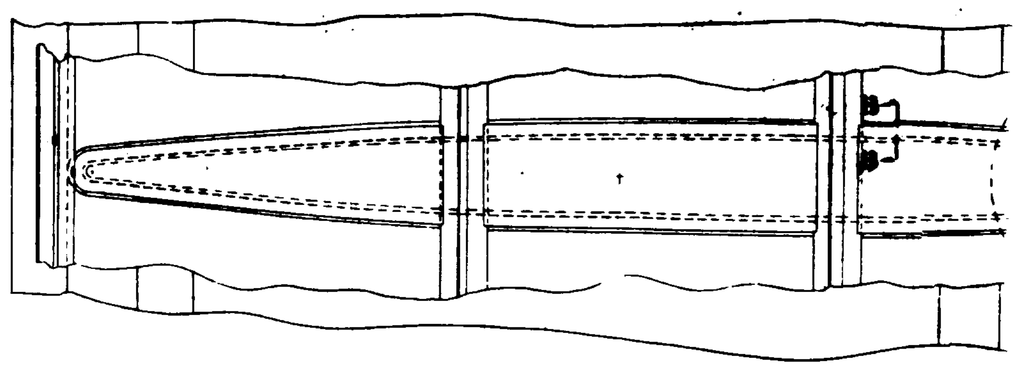
155-B


CIRCUMFERENTIAL SHEAR PANELS
MATL: TI 6AL 4V
OUTER RING
4 PLACES
MATL: TI 6AL 4V
SECTION H-H
STIFFENER
MATL: TI 6AL 4V
SECTION T-T
2 PLACES
OUTER RING
2 PLACES
MATL: TI 6AL 4V
SECTION J-J
J
H
T
E
C
ANE
PLACES
ATL: TI 6AL 4V
RADIAL SHEAR PANEL
MATL: TI 6AL 4V
MOUNT PLATE
MATL: TI 6AL 4V
STIFFENER
4 PLACES
MATL: TI 6AL 4V
STIFFENER
MATL: TI 6AL 4V
SECTION C-C
8 PLACES
RADIAL SHEAR PANEL
MATL: TI 6AL 4V
SECTION E-E

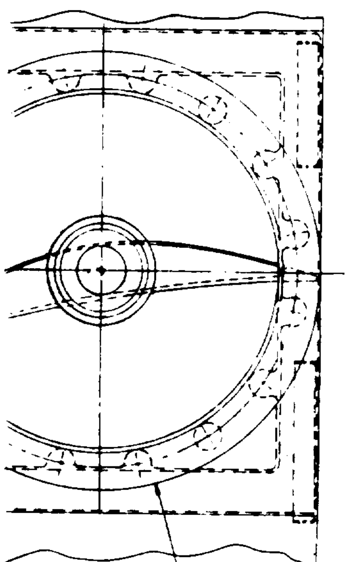
5 - B

155-C

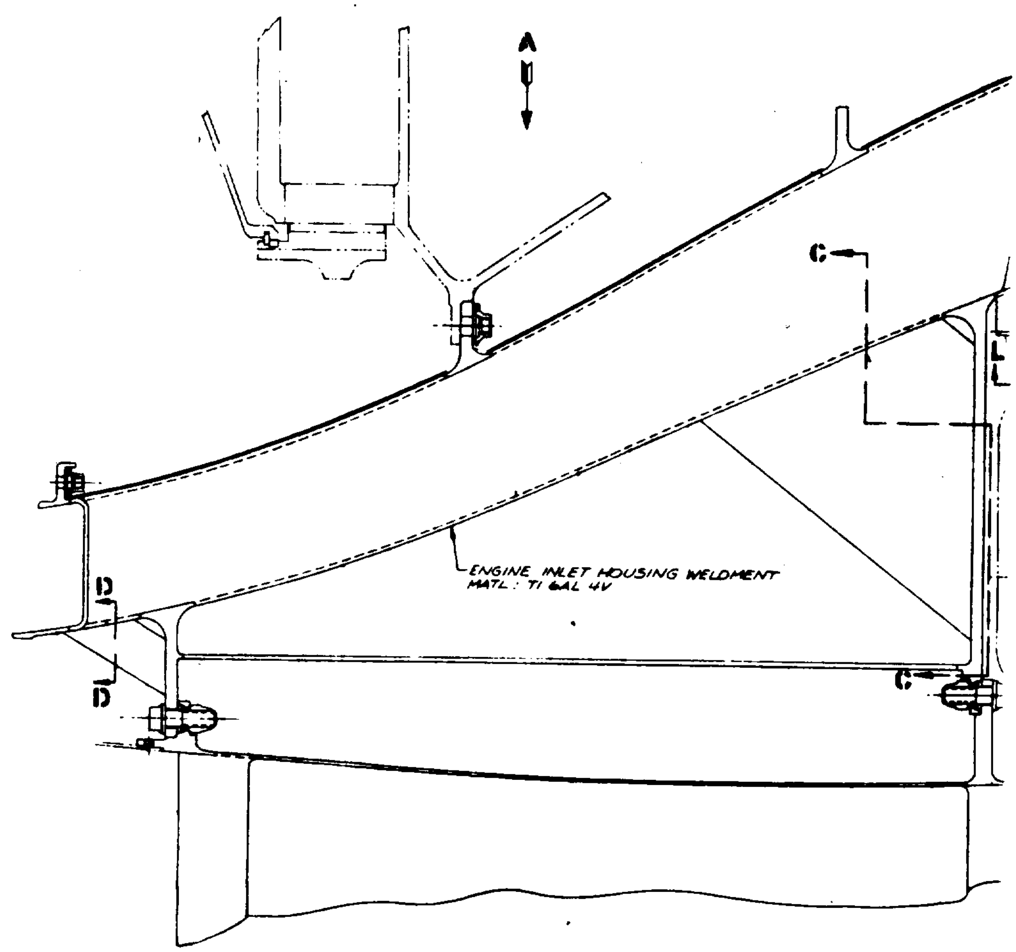
SECTION T-T
PLACES



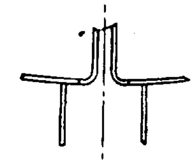
VIEW DIRECTION ARROW A



155-C



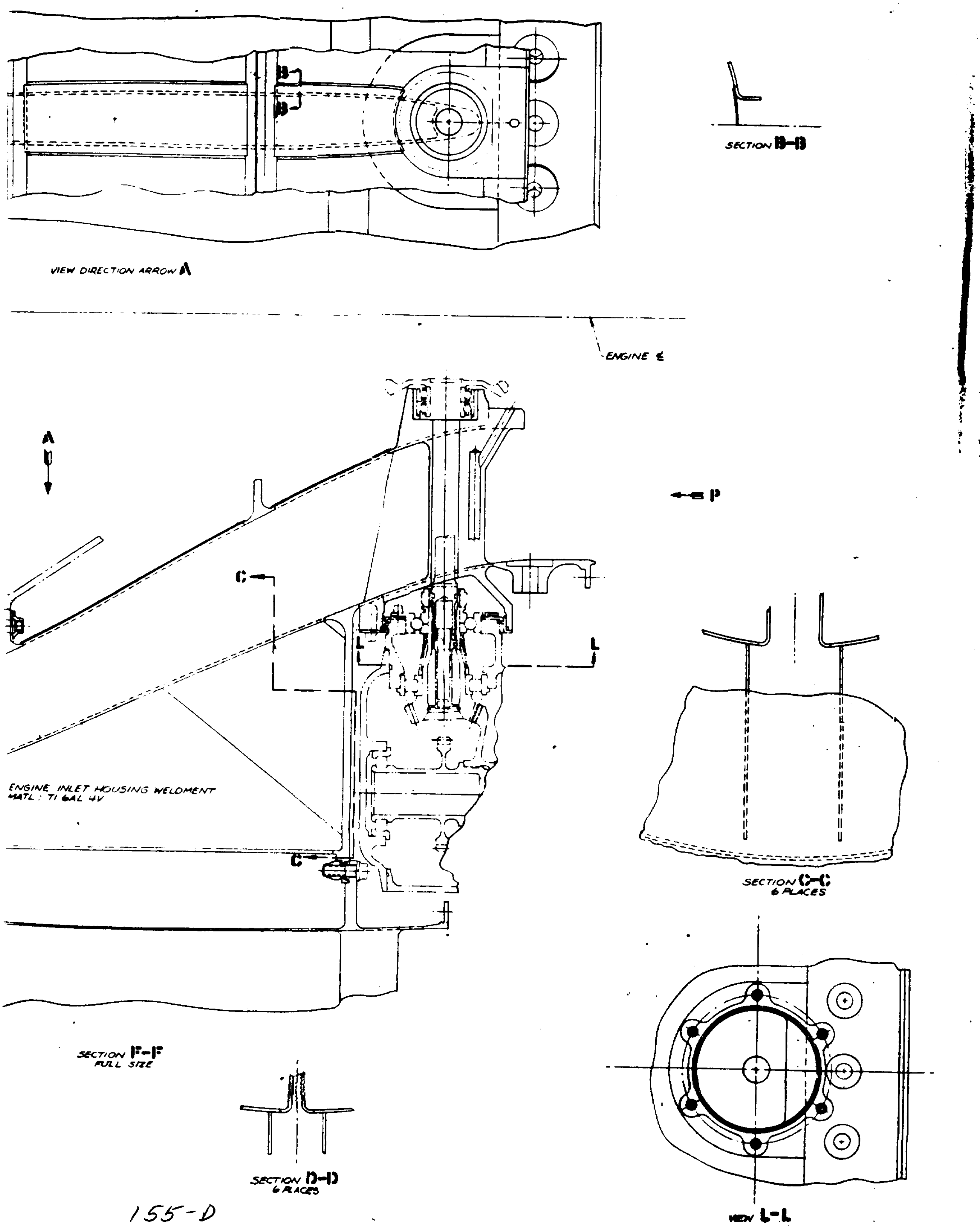
SECTION F-F
FULL SIZE



SECTION D-D
6 PLACES

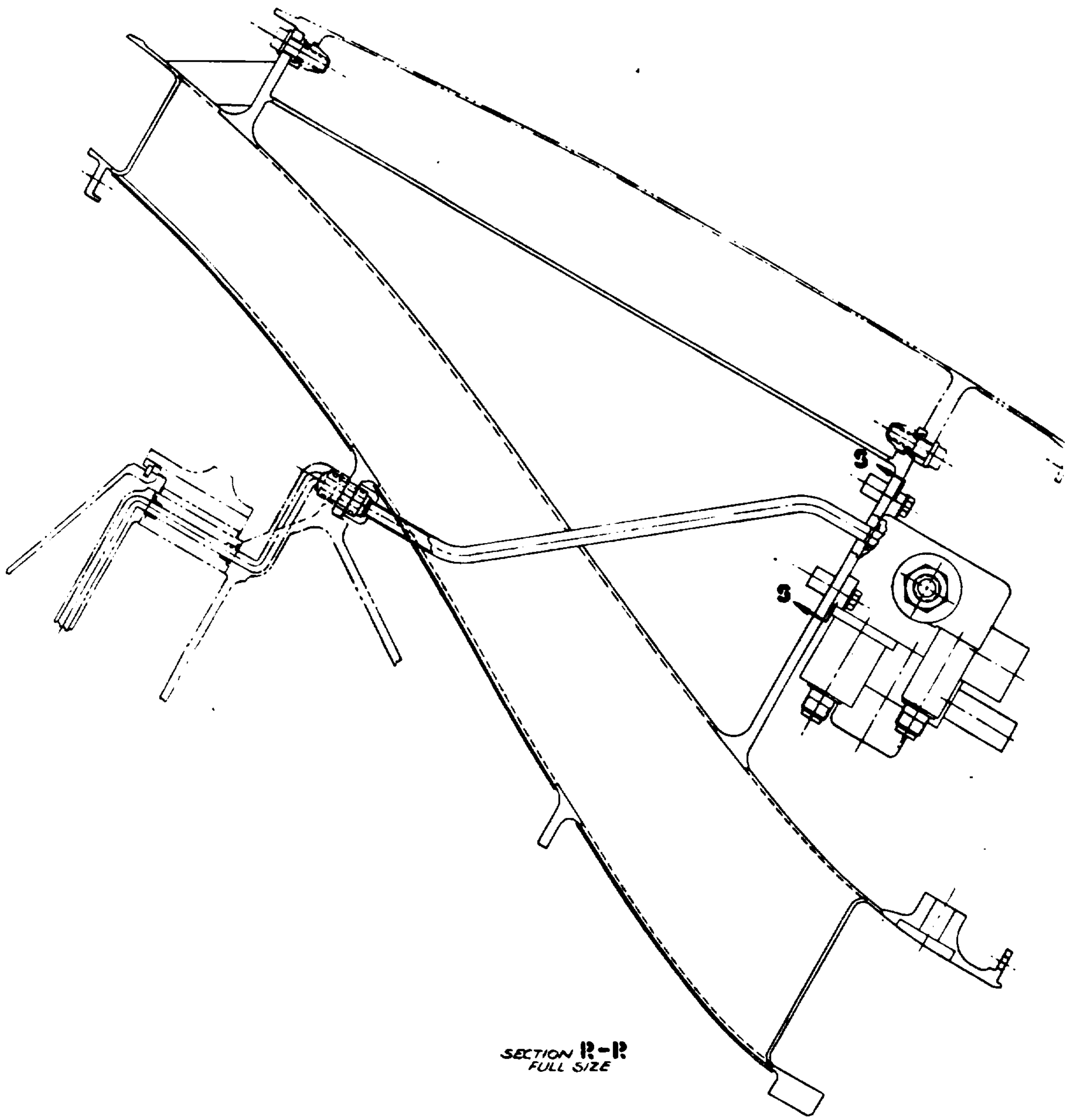
155-D

F



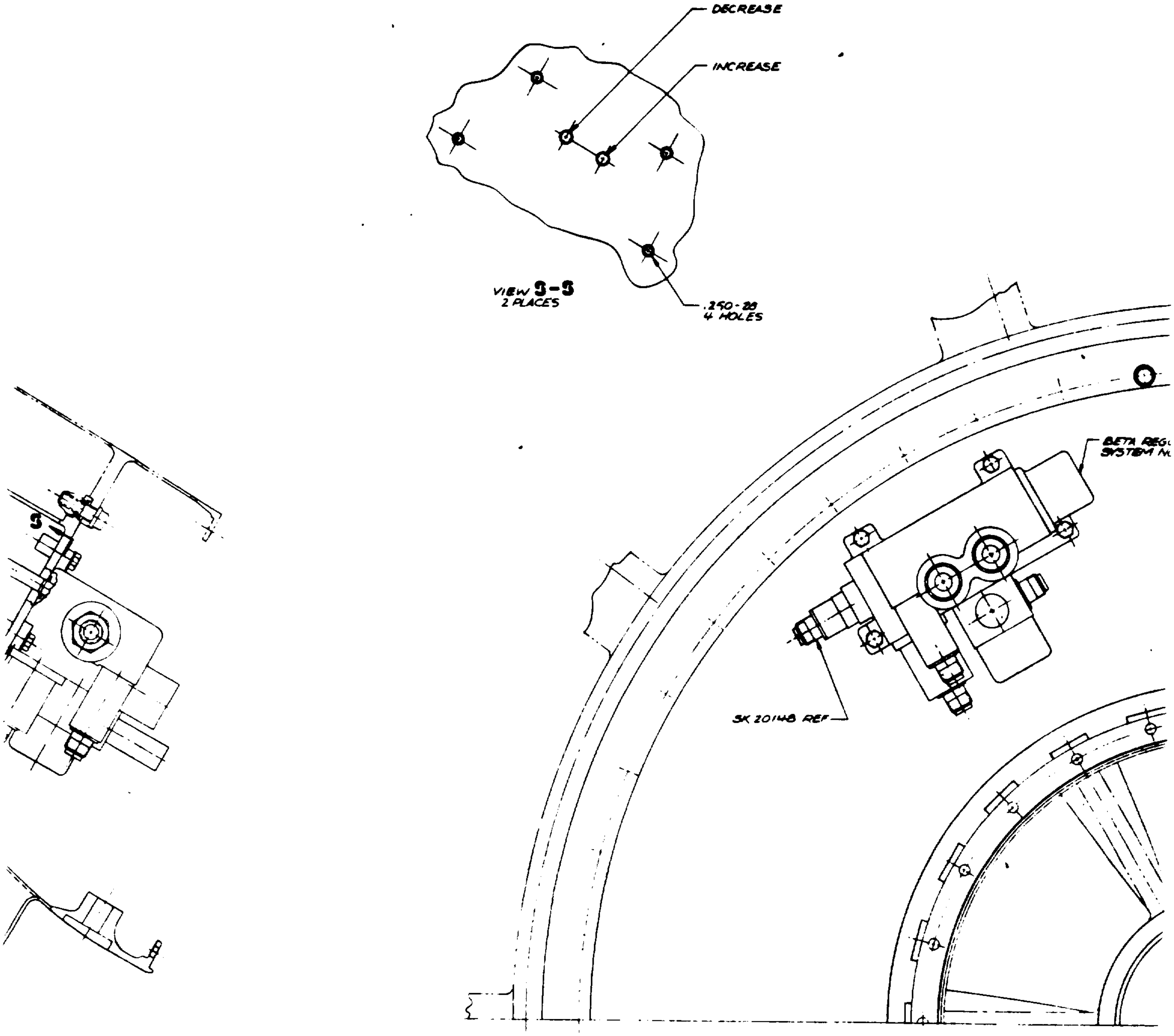
155-D

Figure 76. PD370-25E front frame (sheet 1 of 2).



SECTION R-R
FULL SIZE

157-A


DECREASE
INCREASE
VIEW S-S
2 PLACES
.250-28
4 HOLES
S
SK 20148 REF

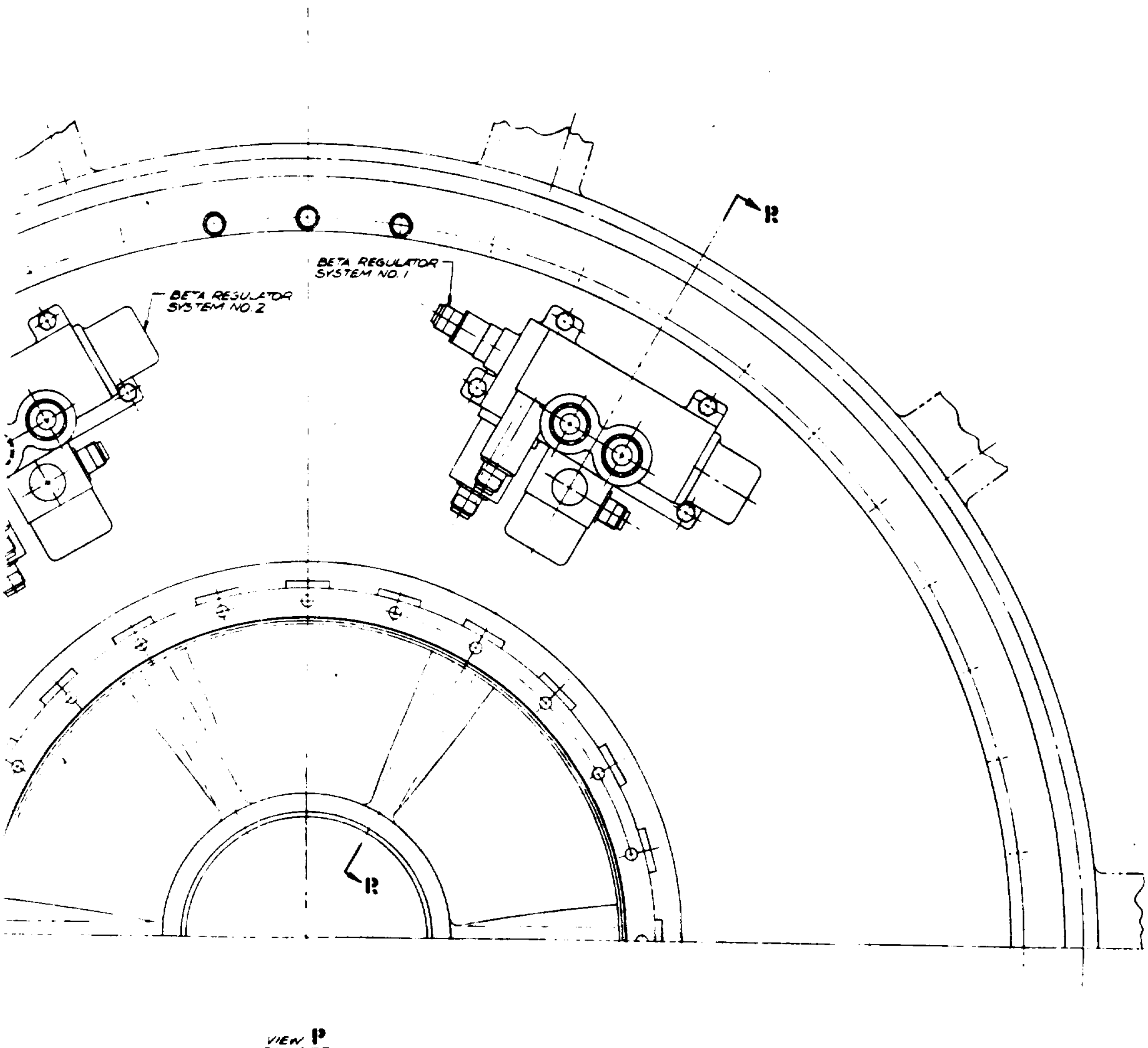


Figure 76. PD370-25E front frame (sheet 2 of 2).

TABLE XLIII. PD370-25E WEIGHT AND CG		
Reference sketch: Figure 73 Cross drive shaft relation to planet system: Aft Mount type: Outer fan case, tilt nacelle Longitudinal distance, fan blade ℄ to cross drive ℄: 26.53 in.		
Engine section	Estimated weight (lb)	$\bar{X}$ (in.)*
Fan inlet	576	22.8
Fan internal housing (fabrication)	202	27.1
Fan shaft internal support	107	12.1
Cross drive system	62	27.7
Planet gear system	139	21.3
Overrunning clutch	26	30.9
Supports and compressor inlet vane	25	42.4
Fan rotor	299	-0.2
Fan nonrotating parts	14	15.0
Fan control	11	35.5
Compressor rotor	127	57.5
Compressor case	117	53.0
Diffuser/combustor	89	69.0
Turbine rotor, HP	86	81.7
Turbine case, HP	44	80.7
Turbine rotor, LP	125	87.0
Turbine case, LP	99	87.2
Turbine rear bearing support	92	94.5
Fuel system	69	53.9
Lube, electrical, piping systems	146	58.3
Accessory drive gearbox	53	37.8
Total weight (no margin)	2508	39.7
Margin	75	
Total engine weight including margin	2583	
*CG datum plane fan blade center line, aft plus.		

WEIGHTS

A summary of the estimated weight breakdown for the PD370-25E engine is given in Table XLIII. The same procedure was followed for calculating these weights as that described for the PD370-25A engine in the preceding section. Again, the result was a total of 1165 lb of well defined weight although this represents only 44% of the weight of this heavier engine assembly.

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XT701-AD-700 ENGINE MODIFICATIONS

As mentioned in previous sections, the XT701 engine is the basic power section for both the PD370-25A and the PD370-25E V/STOL RTA engines. A minimum number of changes appeared appropriate for the XT701 in this RTA V/STOL application. They fell into the following areas:

- Mechanical modifications (Figures 77 and 78)
  - Internal scavenging mods for the tilt nacelle configuration
  - Replacement of compressor inlet housing
  - Elimination of torquemeter
- Control changes

MODIFICATIONS FOR LIFT/CRUISE ENGINE—FIXED NACELLE

Inlet Housing and Accessory Gearbox Mount

The XT701 compressor inlet housing was eliminated for the PD370-25A design. All required functions of this structure are now performed by the main fan structure. In summary, these functions include the following:

- Support for front end of compressor
- Accessory drive
- Inlet guide vane location
- Accessory gearbox mounting
- Front engine mounts

Turbine Changes

An analysis of the turbine section showed that no changes would be required for it to function as the gas generator section of a lift/cruise turbofan engine.

Effects of Ram on Engine Casings

Compressor

An analysis of the compressor casing under maximum ram conditions (sea level, 0.8 M_N) disclosed that a minor problem would exist at the horizontal splitline flange near the latter stages. The increased pressure level at this point would tend to introduce a bending moment in these flanges and, as a result, the flange face undercut sealing surfaces would separate. However, the simplest solution to this problem would be to increase the clamping force being applied by the flange bolts. This could easily be accomplished by specifying a bolt stretch dimension, or a number of nut rotations beyond the initial clamp-up torque rather than a standard nut torque.

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Standard torque values permit a relatively wide variation in clamping force because torque values are a function of the coefficient of friction of each nut, bolt, and flange interface and vary widely as a function of surface finish, type or absence of lubrication, etc. The resultant clamping force, for stress analysis purposes, must therefore be assumed to be on the lower side of this tolerance spread. A specific bolt stretch dimension would ensure that the required clamping force was applied to prevent the flange sealing faces from separating.

Diffuser

An analysis of the diffuser casing under maximum ram conditions (sea level, 0.8 M_N) disclosed that the most critical parameter for this titanium component is the temperature at which it will be operating. The property of 6Al-4V titanium most sensitive to temperature is creep strain; therefore, an accurate estimate of the actual operating temperature of the casing is important. Actual case temperature measurements were extrapolated to the RTA maximum conditions, as shown in Figure 79. This curve shows that the casing temperature spread, at a compressor discharge temperature of 818°F (sea level, 0.8 M_N), ranges from 685 to 785°F. The maximum temperature of 785°F occurs approximately 7.5 in. aft of the diffuser front flange. The operating time at this temperature is a function of the duty cycle described in Figure 7, and the equivalent life calculation, described subsequently under the "Turbine Life" heading, which results in a total of 75 hours at the maximum temperature condition. This combination of temperature and time is within the design criteria of -3σ 0.5% strain, as shown in Figure 80, and should present no problem in the RTA installation.

The remaining engine casings, including the turbine casing and rear support, are not affected by the RTA ratings because they are not stress- or temperature-limited components.

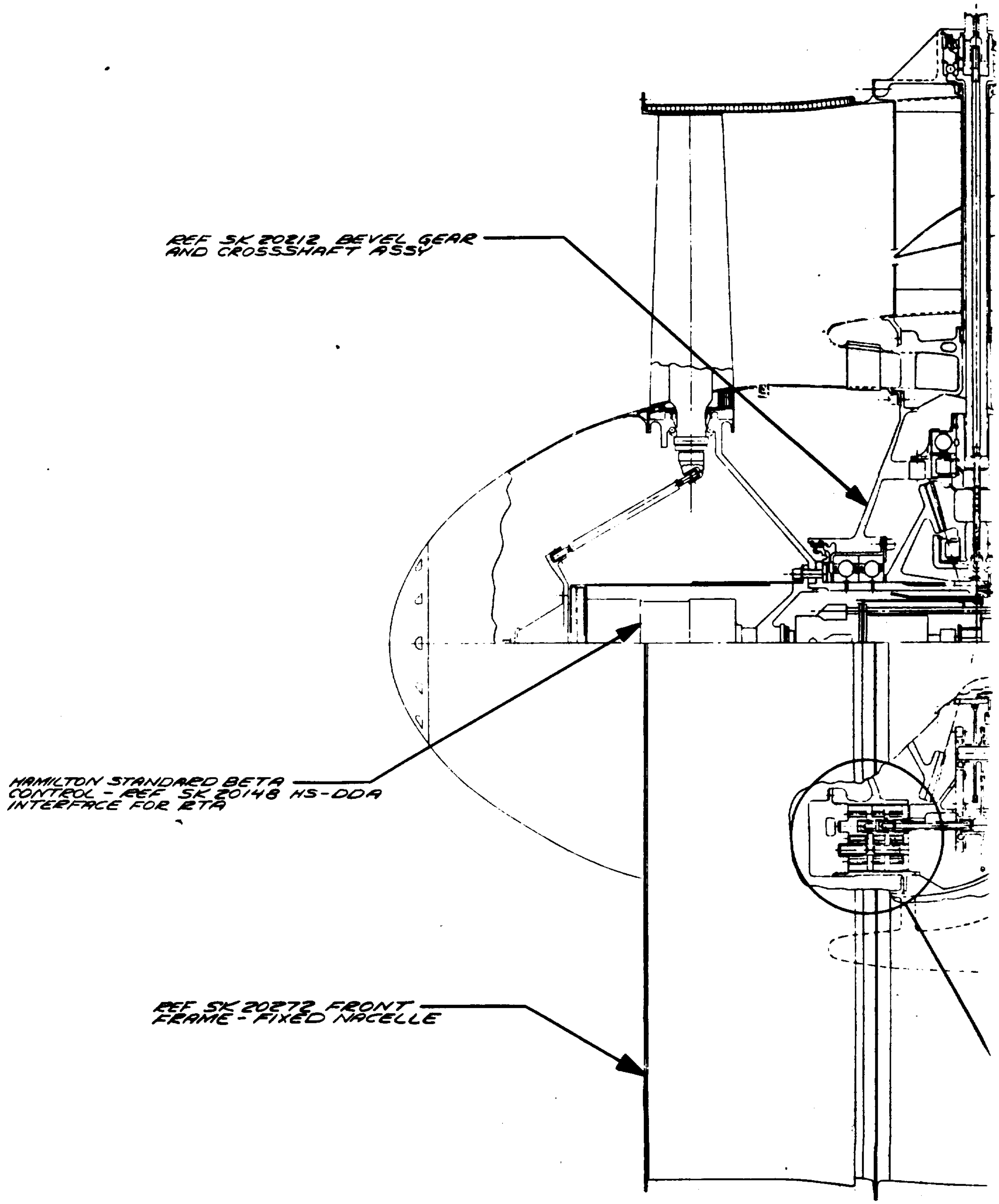
Engine Controls

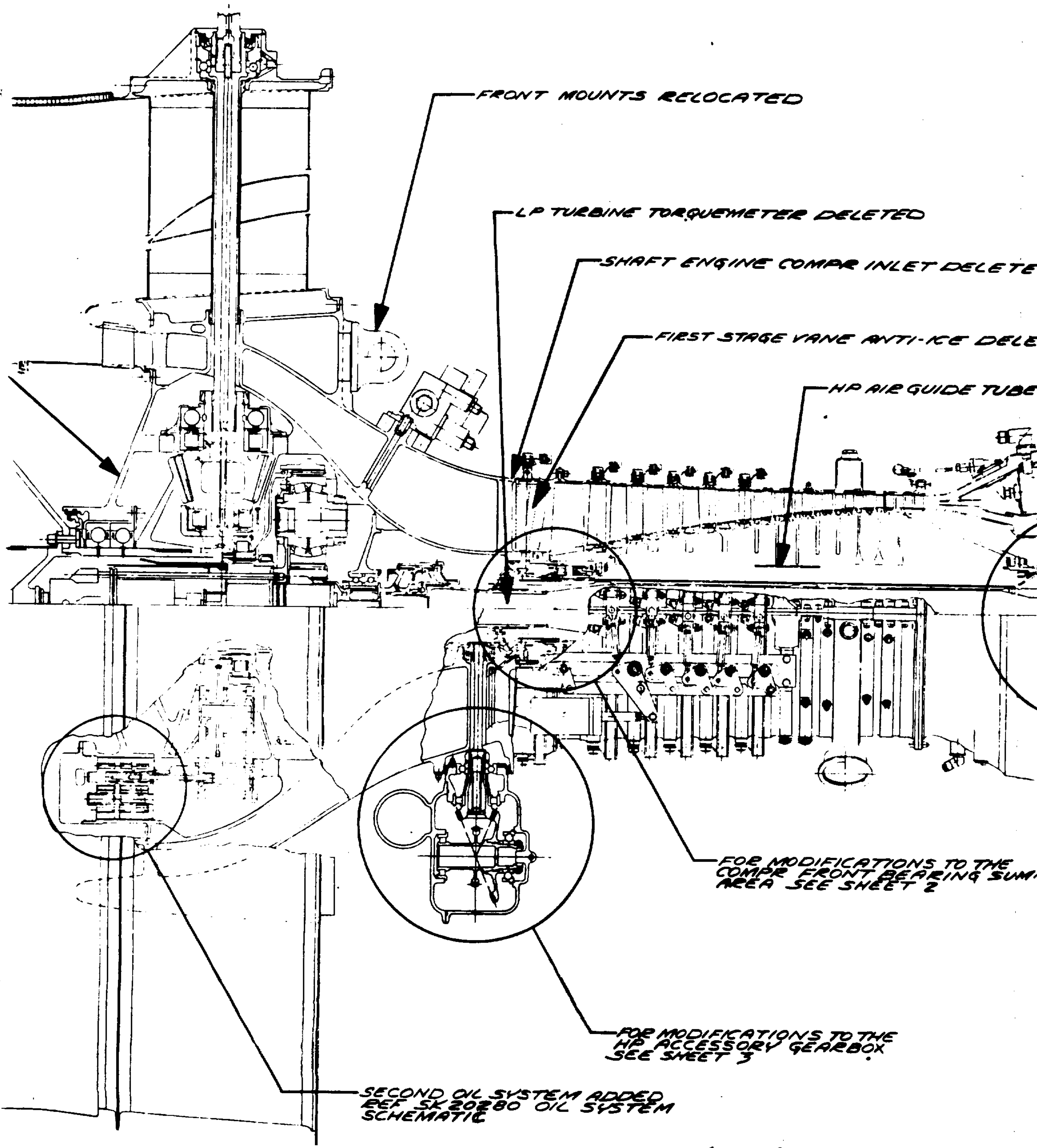
A basic constraint in the design was the maximum use of XT701 control system components to minimize the development cost. However, the relationship of the RTA propulsion and flight control systems in vertical and transition modes necessitates a similar degree of reliability. Consequently, the XT701 control electronics had to be replaced to accomplish the added fan pitch control task and to achieve fail-safe operation.

To attain this accomplishment, a triply-redundant digital engine controller will replace the electronic control. A digital system is used because of its more powerful logic and computational functions and its continually decreasing cost. The functions of the XT701 power management control have been incorporated into each of the digital controls.

The hydromechanical fuel control units are modified to incorporate new CVG* and fuel schedules and to increase the authority of the twin input. This provides satisfactory tolerance to servovalve

*Compressor Variable Geometry


REF SK 20212 BEVEL GEAR AND CROSSSHAFT ASSY
HAMILTON STANDARD BETA CONTROL - REF SK 20148 HS-DDA INTERFACE FOR RTA
REF SK 20272 FRONT FRAME - FIXED NACELLE



FRONT MOUNTS RELOCATED
LP TURBINE TORQUEMETER DELETED
SHAFT ENGINE COMPR INLET DELETEL
FIRST STAGE VANE ANTI-ICE DELE.
HP AIR GUIDE TUBE.
FOR MODIFICATIONS TO THE COMPR FRONT BEARING SUM AREA SEE SHEET 2
FOR MODIFICATIONS TO THE HP ACCESSORY GEARBOX SEE SHEET 3
SECOND OIL SYSTEM ADDED REF SK 20280 OIL SYSTEM SCHEMATIC

163-B

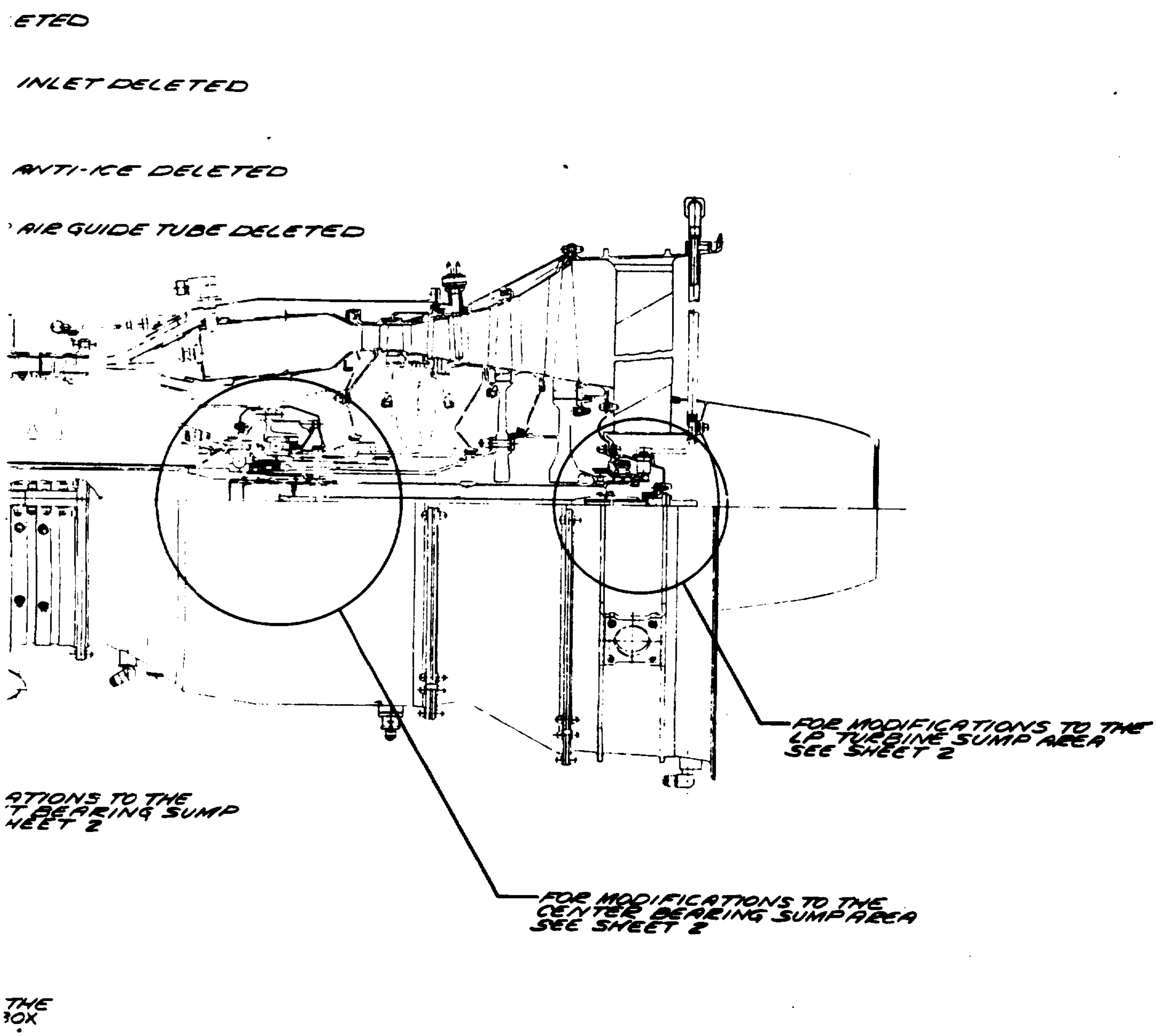
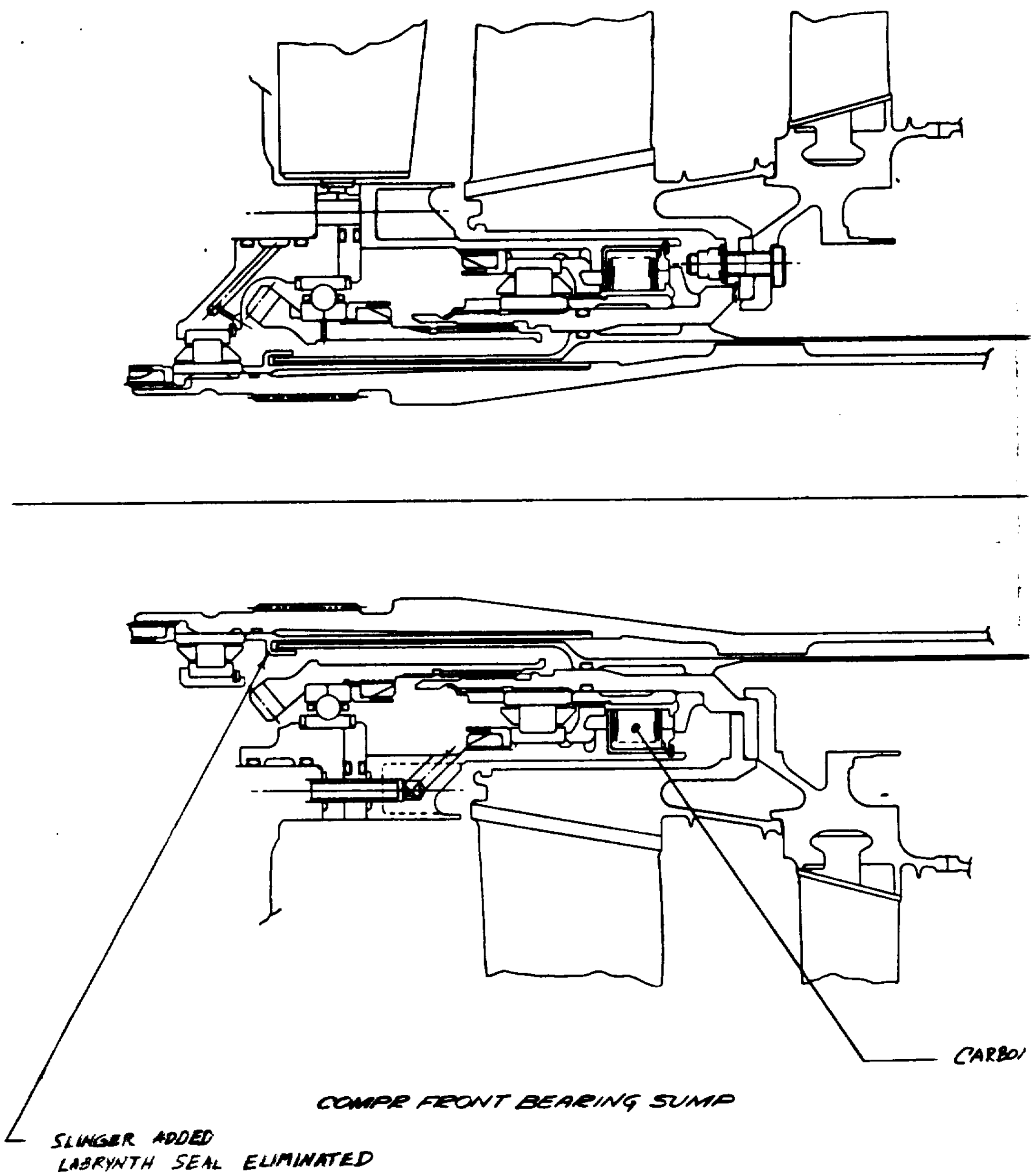
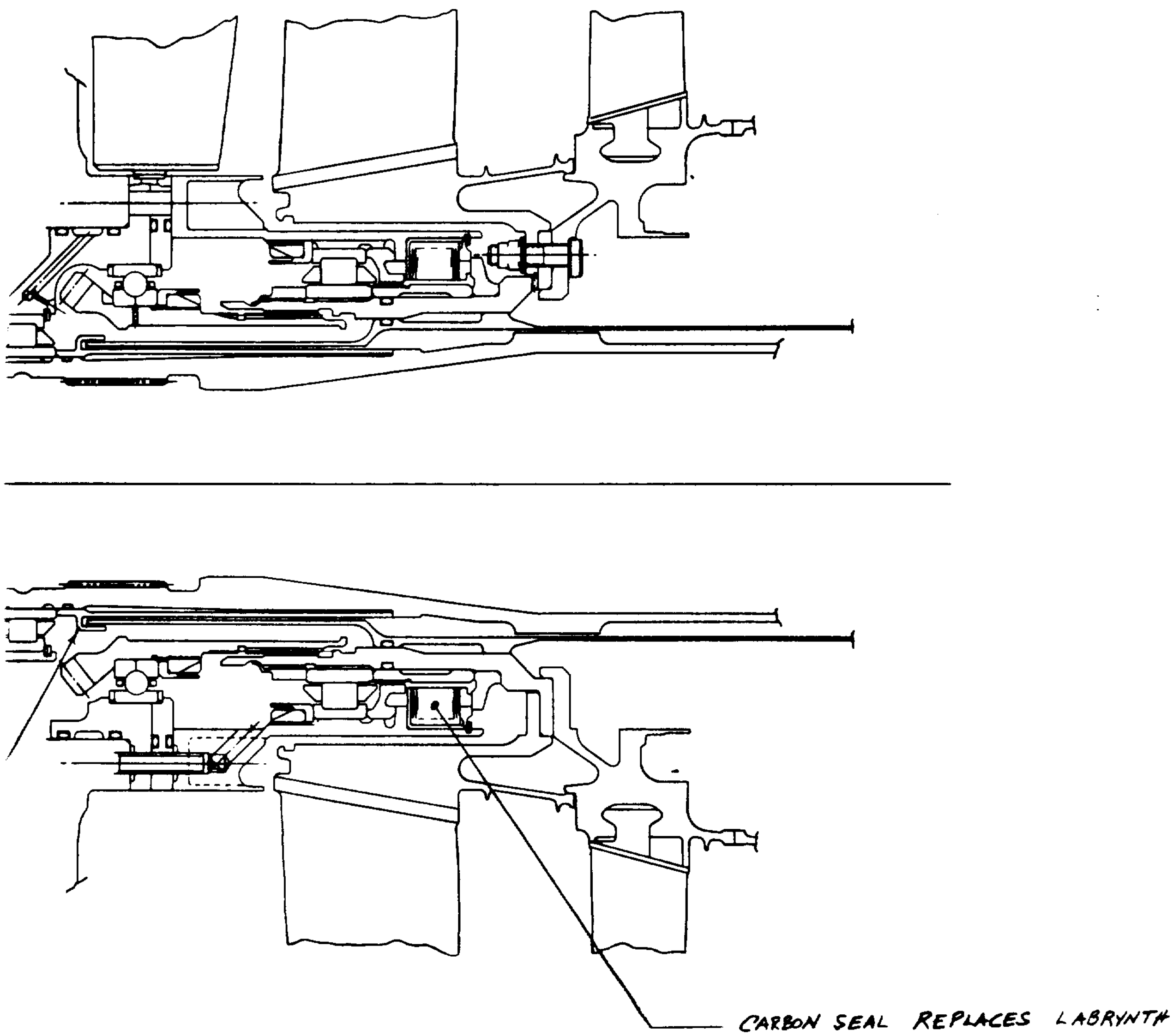


Figure 77. XT701-AD-700 engine modifications.

C



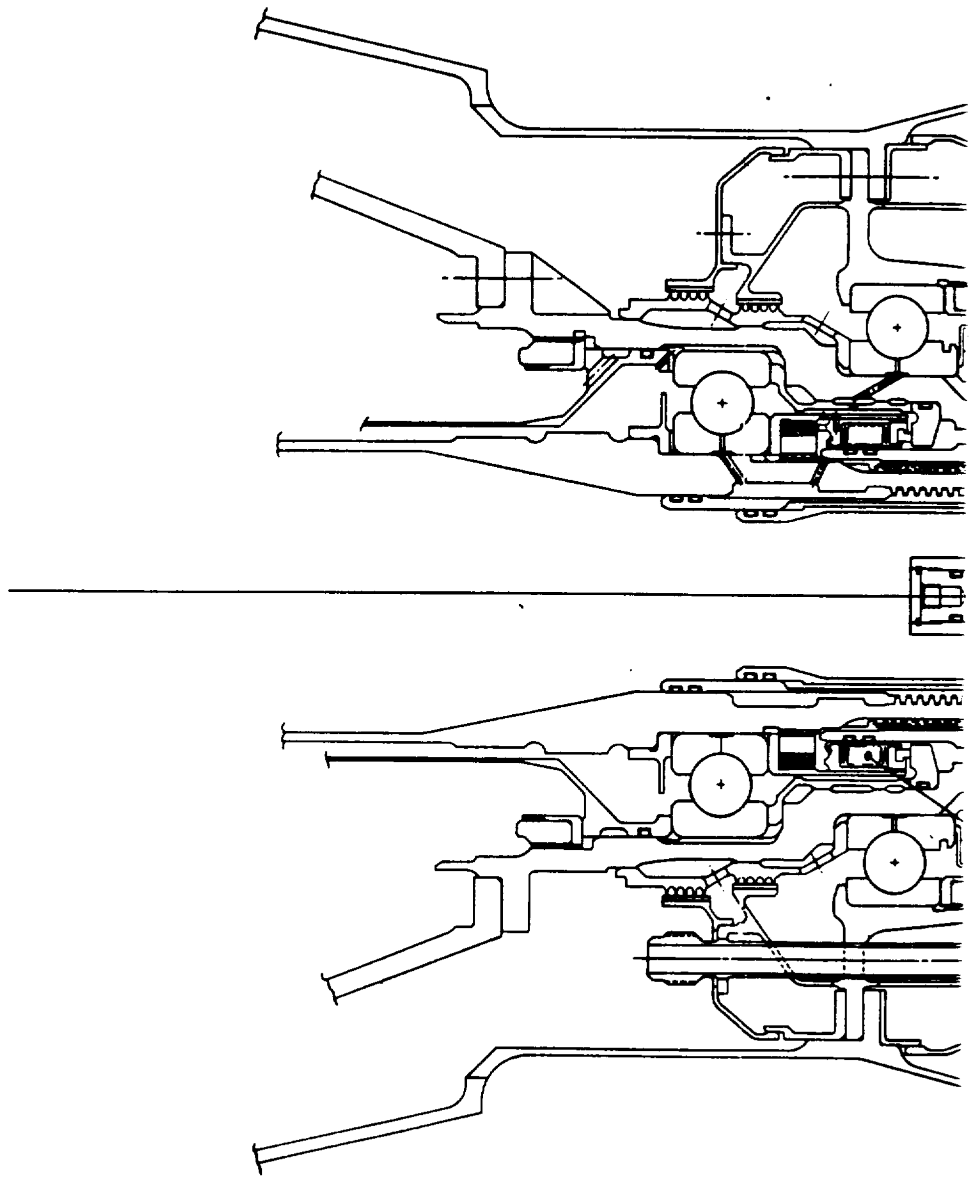
COMPR FRONT BEARING SUMP



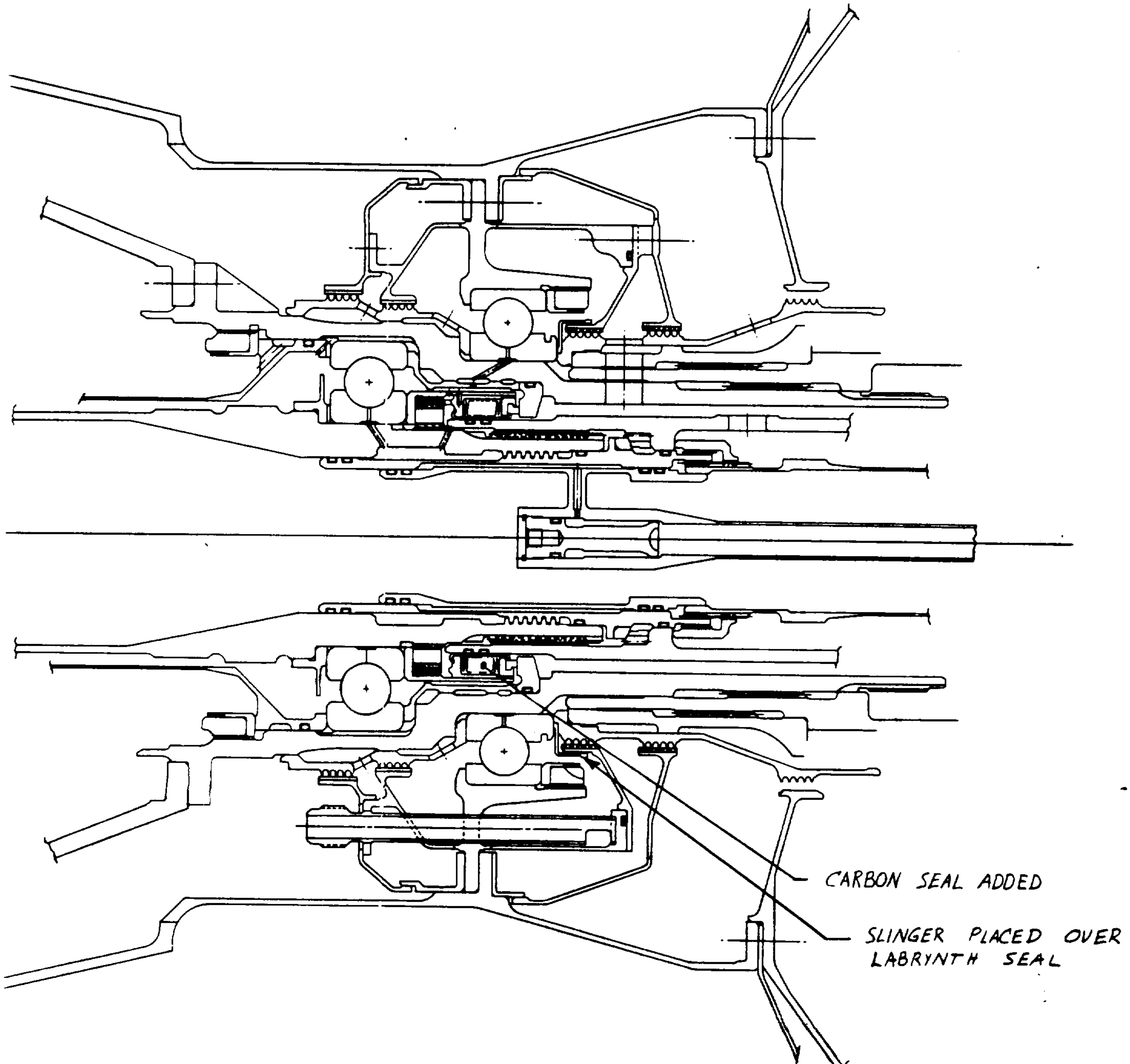
COMPR FRONT BEARING SUMP

ED
EAL ELIMINATED

REPLACES LABRYNTH



CENTER BEARING SUMP

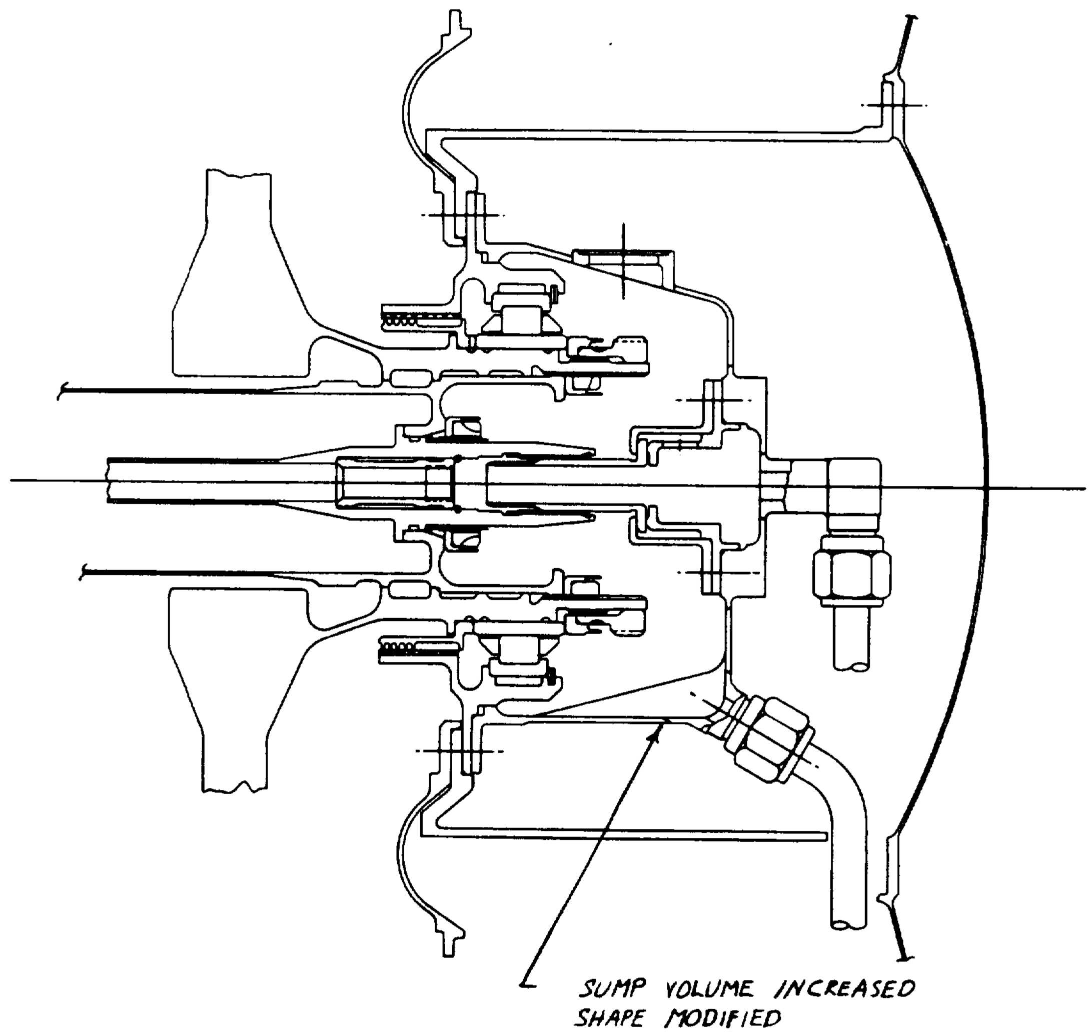


CENTER BEARING SUMP

165-B

ADDED

ᴾLACED OVER
⁴ SEAL



C

Figure 78. Tilt nacelle internal scavenging modifications.

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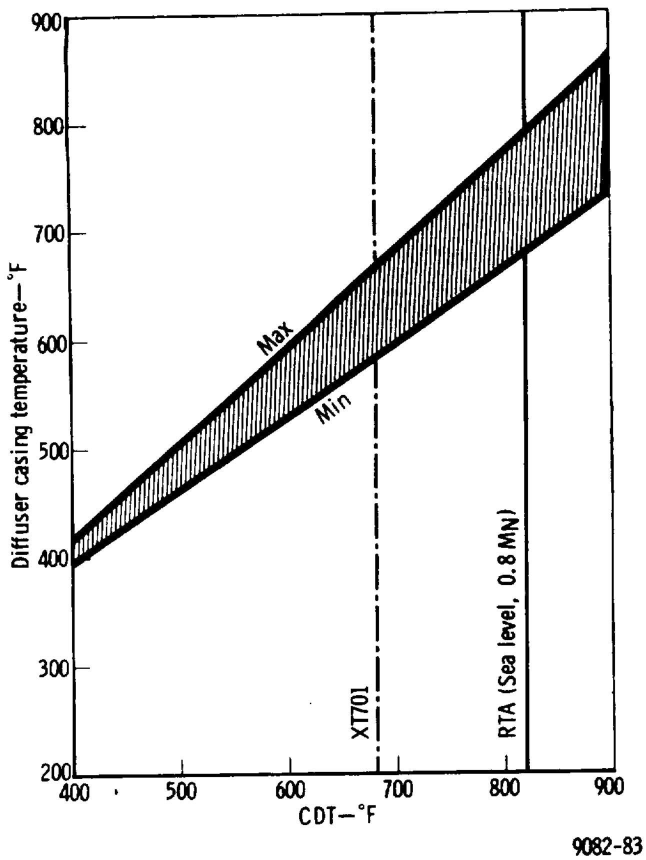

Figure 79. Diffuser casing temperature.

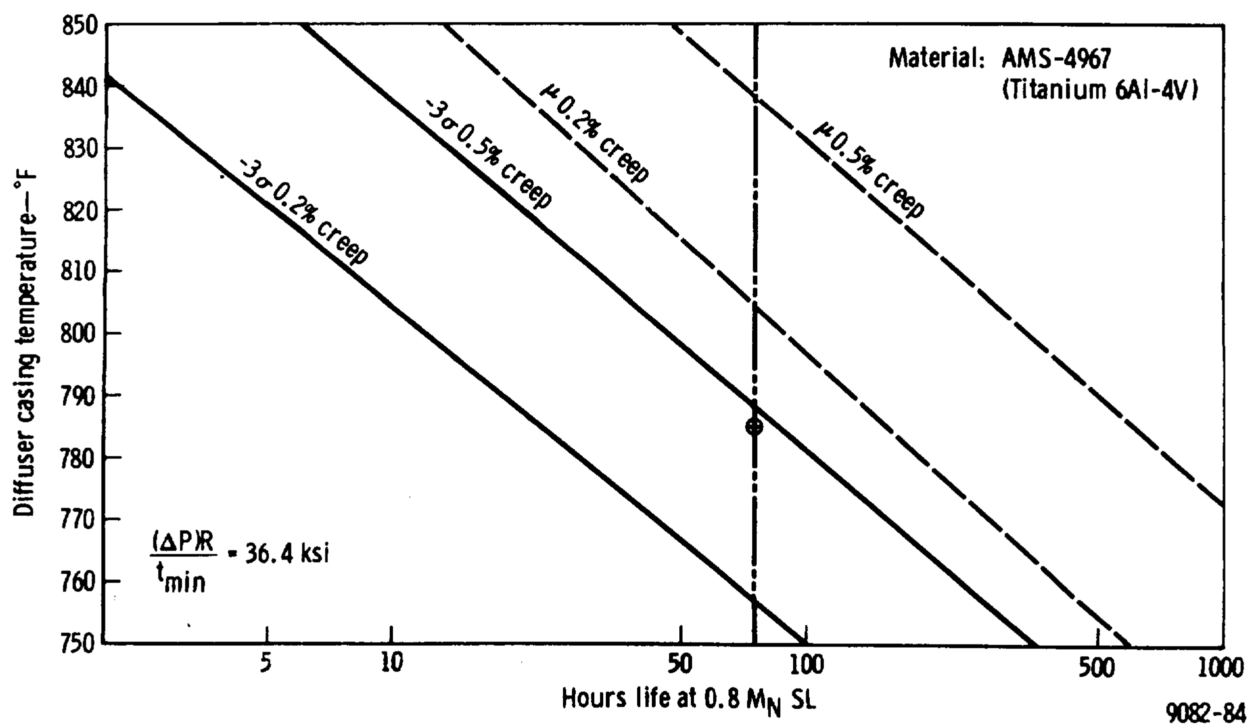

Figure 80. Diffuser casing life.

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failure. During XT701 testing, the hydro unit demonstrated very high reliability, so that no backup fuel metering system is planned. Figure 81 shows the RTA propulsion system control schematically.

Rotor Dynamics

The XT701 power section was used in a dynamic analysis for the NASA/Navy V/STOL engine. A mass elastic model of the engine general arrangement was prepared for input to a DDA computer program, a beam element analysis tool routinely used for rotor case analysis. Figure 82 is a geometric representation of the engine model used in the analysis. The fan is contra-rotating with respect to the remainder of the rotor system.

Critical speeds for an HP-excited system are shown in Figures 83 and 84. The first three modes are essentially rigid body modes. The fourth mode, at 6407 rpm, involves LP turbine motion and is controlled by the spring rate of the LP turbine rear isolator. The fifth and sixth modes are coupled system modes involving motion of the casing and the LP and HP rotors. At 13,487 rpm, the predominant motion is that of the fan. There is an HP mode at 16,593 rpm that is similar to the one existing in the XT701. The last two modes are LP system modes and well above the operating range.

For LP excitations, the system has critical speeds as shown in Figures 85 and 86. The modes involving significant LP motion are the fourth, fifth, and sixth. The fourth mode is the LP turbine mode, dependent on the rear LP turbine isolator. Motion of the casing and of the HP and LP system constitutes the fifth mode, and out-of-phase motion of the case and the LP turbine makes up the sixth mode. The seventh mode is basically fan motion, and the remainder of the modes are sufficiently above 100% speed to be of little concern.

Figures 87 and 88 show the critical speeds for the fan system. The first two modes are basically rigid body modes, and the third mode involves LP turbine motion. The remaining modes, including the fan mode at 13,386 rpm, fall well beyond 100% speed—3534 rpm—and should not be a problem.

The mass elastic model was used to determine response to unbalance for the V/STOL engine. The vibration response for expected levels of unbalance were low and acceptable. The dynamic analysis indicated a satisfactory mass-elastic arrangement.

Torquemeter

The modification to the front end of the XT701 engine involved removing the torquemeter. This component was unnecessary for the control system envisioned.

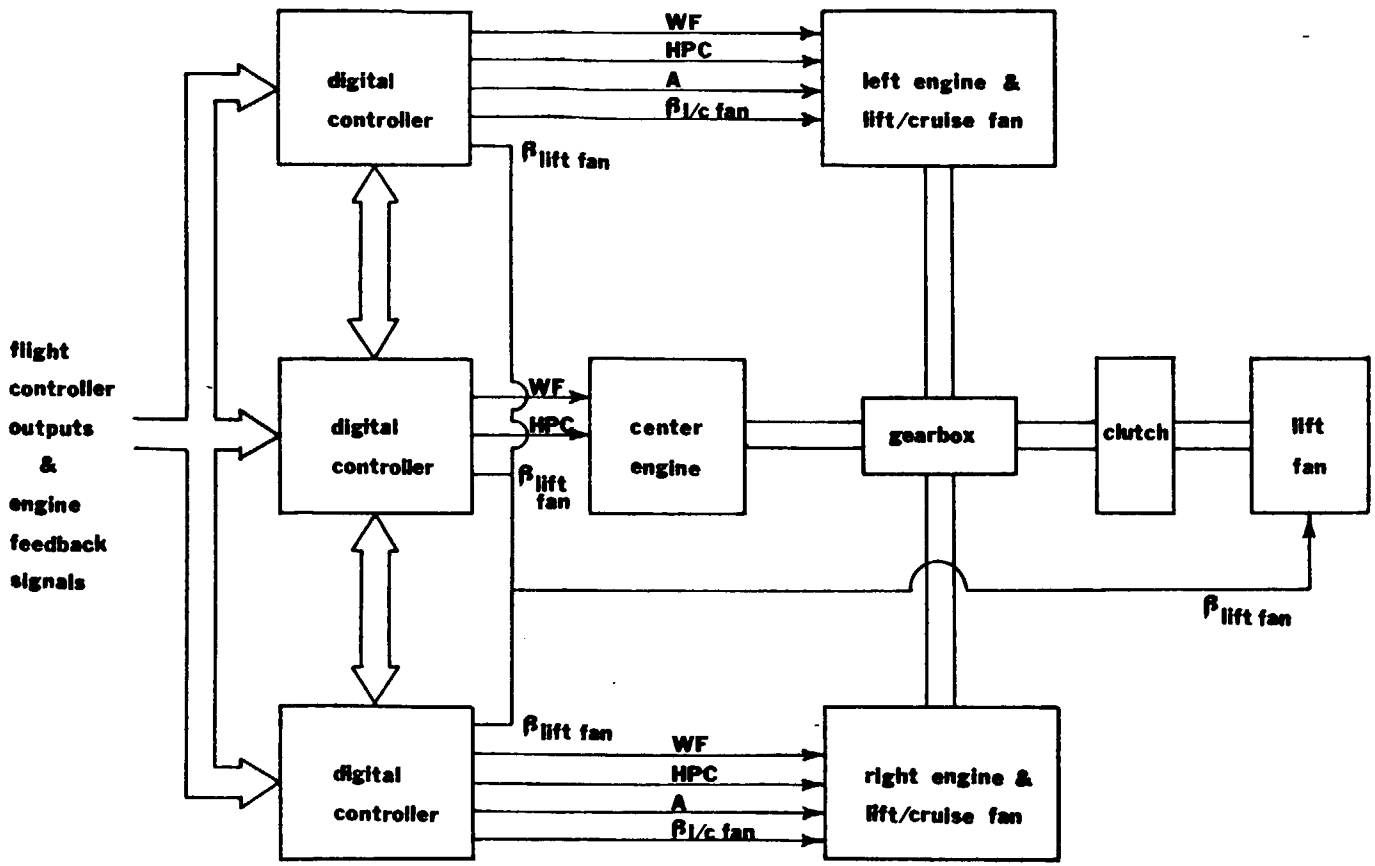


Figure 81. RTA propulsion system control schematic.

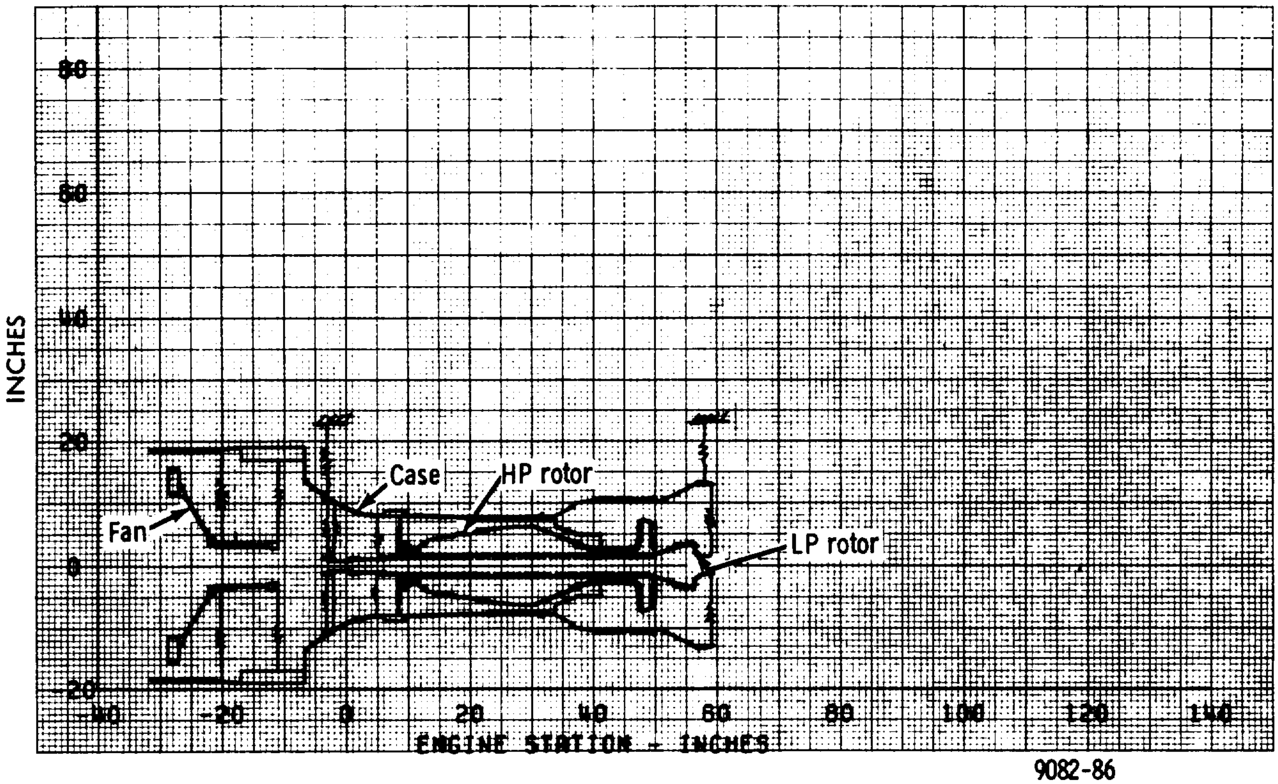


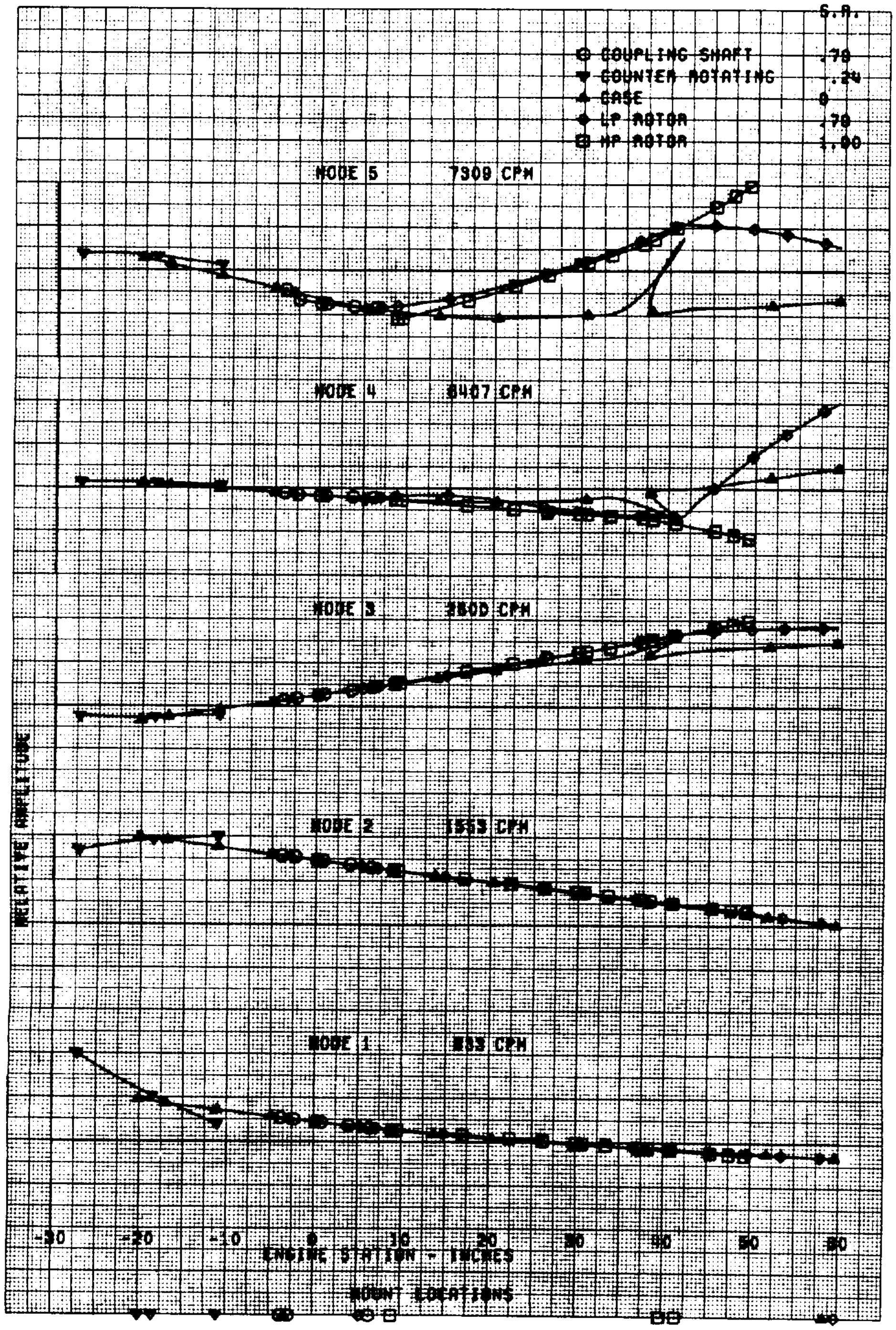
Figure 82. PD370-25 geometric representation.

Thrust Balance and Vent System

The XT701 free-shaft engine was analyzed as a two-spool engine with a 1.218 fan pressure ratio. The cycle used was maximum VTO power. The variable-pitch fan was not integrated into the modeling circuit because aerodynamic blade loads were not clearly defined and because the shaft loads from this component are not transferred to the HP-LP center bearing system. Therefore, only the effect of the fan discharge conditions was considered to affect gas generator and power sections.

The following results were obtained in the preliminary thrust balance analysis of center bearing loads:

LP system load = 4573 lb rearward
HP system load = 1112 lb forward
Net HP system load = 3461 lb rearward



9082-87

Figure 83. HP system critical speeds, modes 1-5.

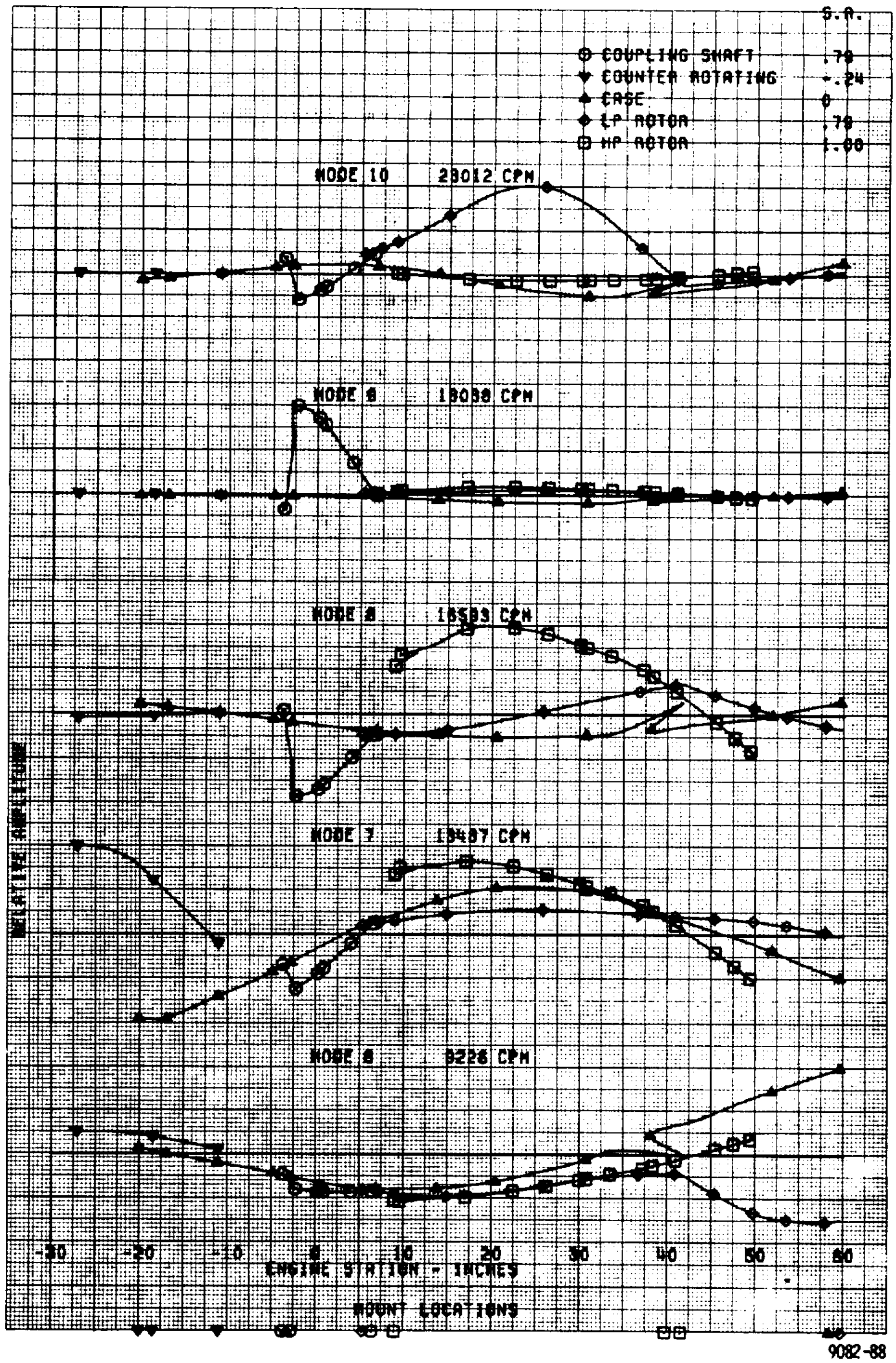


Figure 84. HP system critical speeds, modes 6-10.

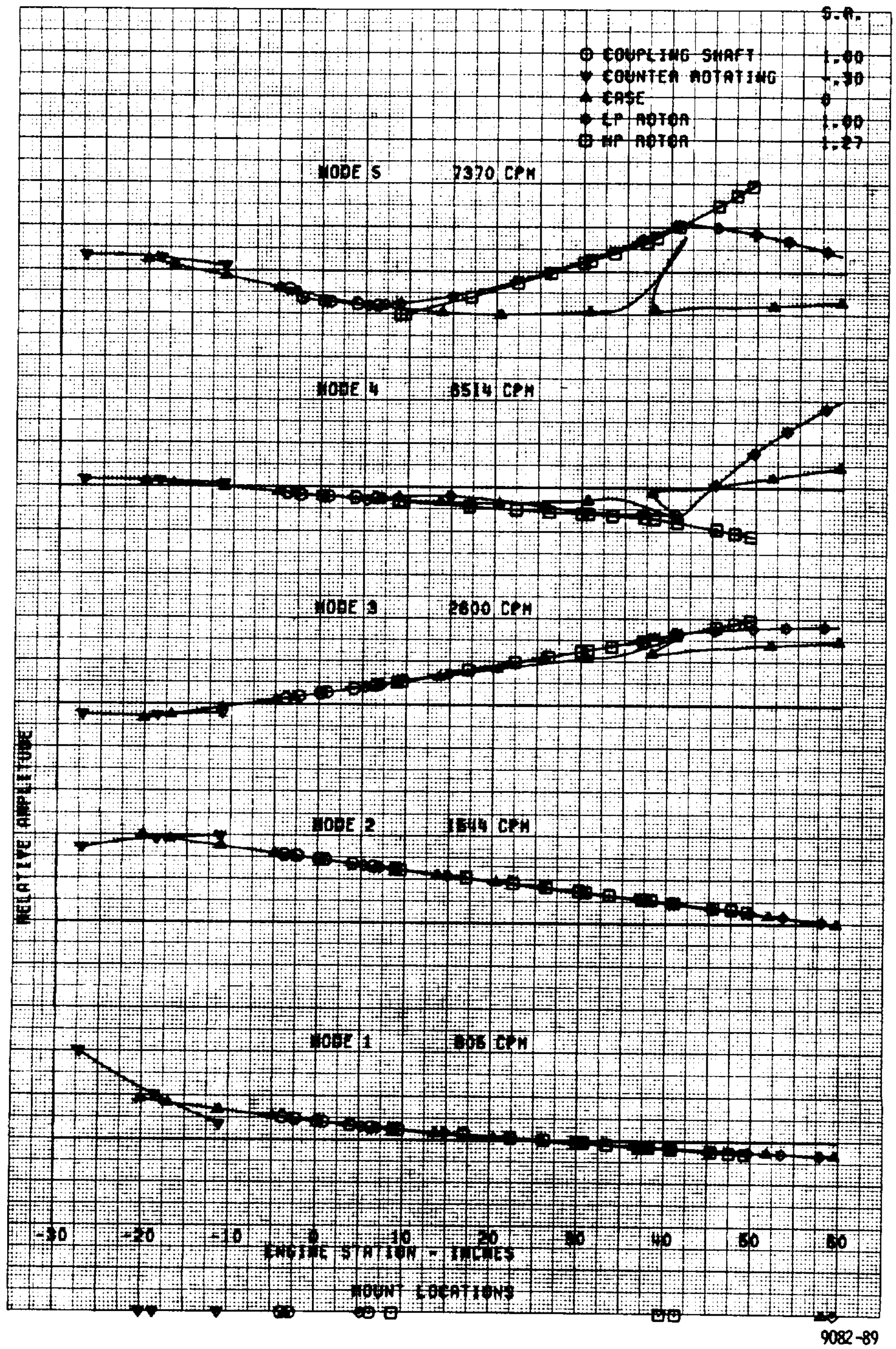
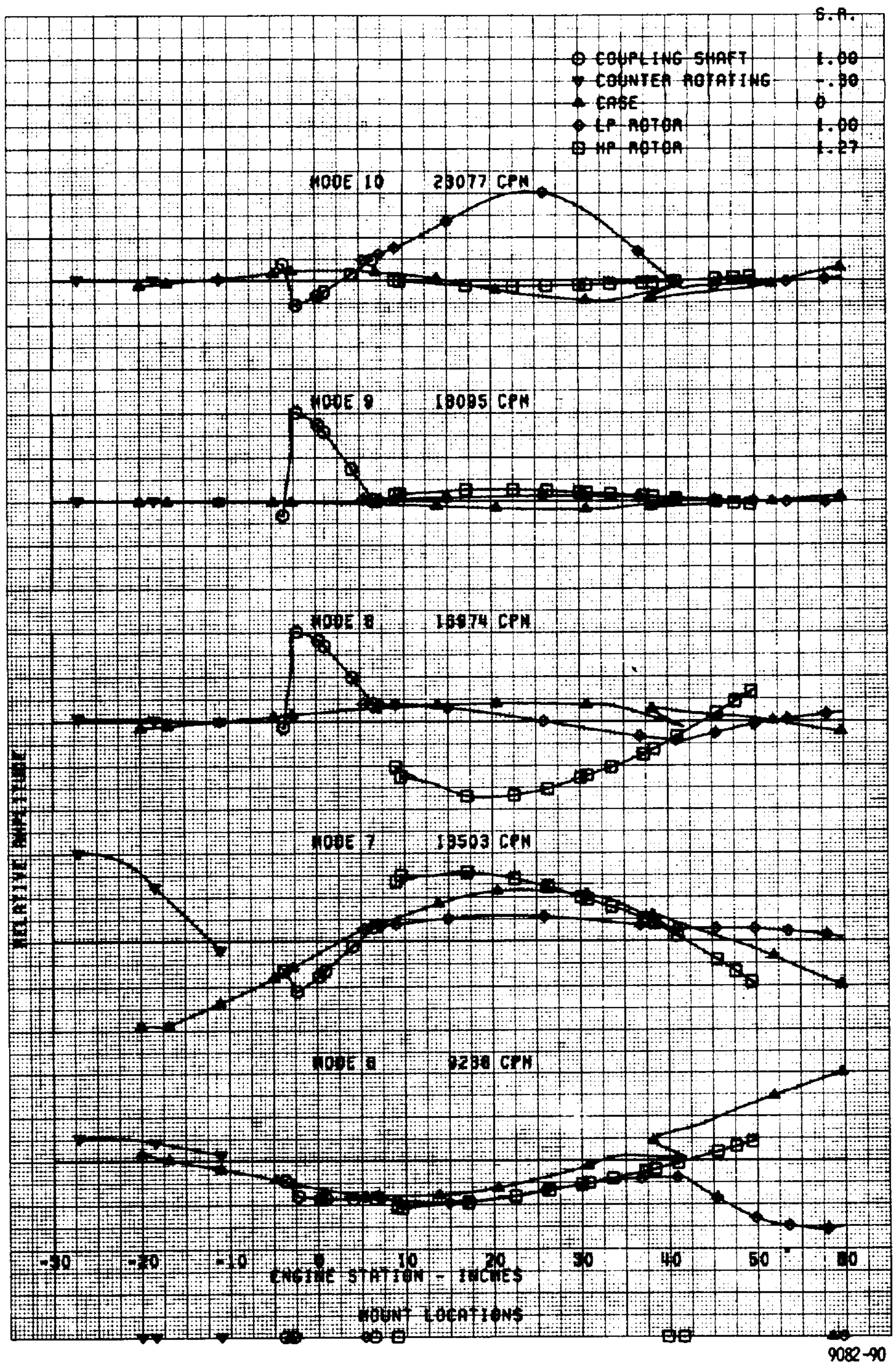


Figure 85. LP system critical speeds, modes 1-5.



9082-90

Figure 86. LP system critical speeds, modes 6-10.

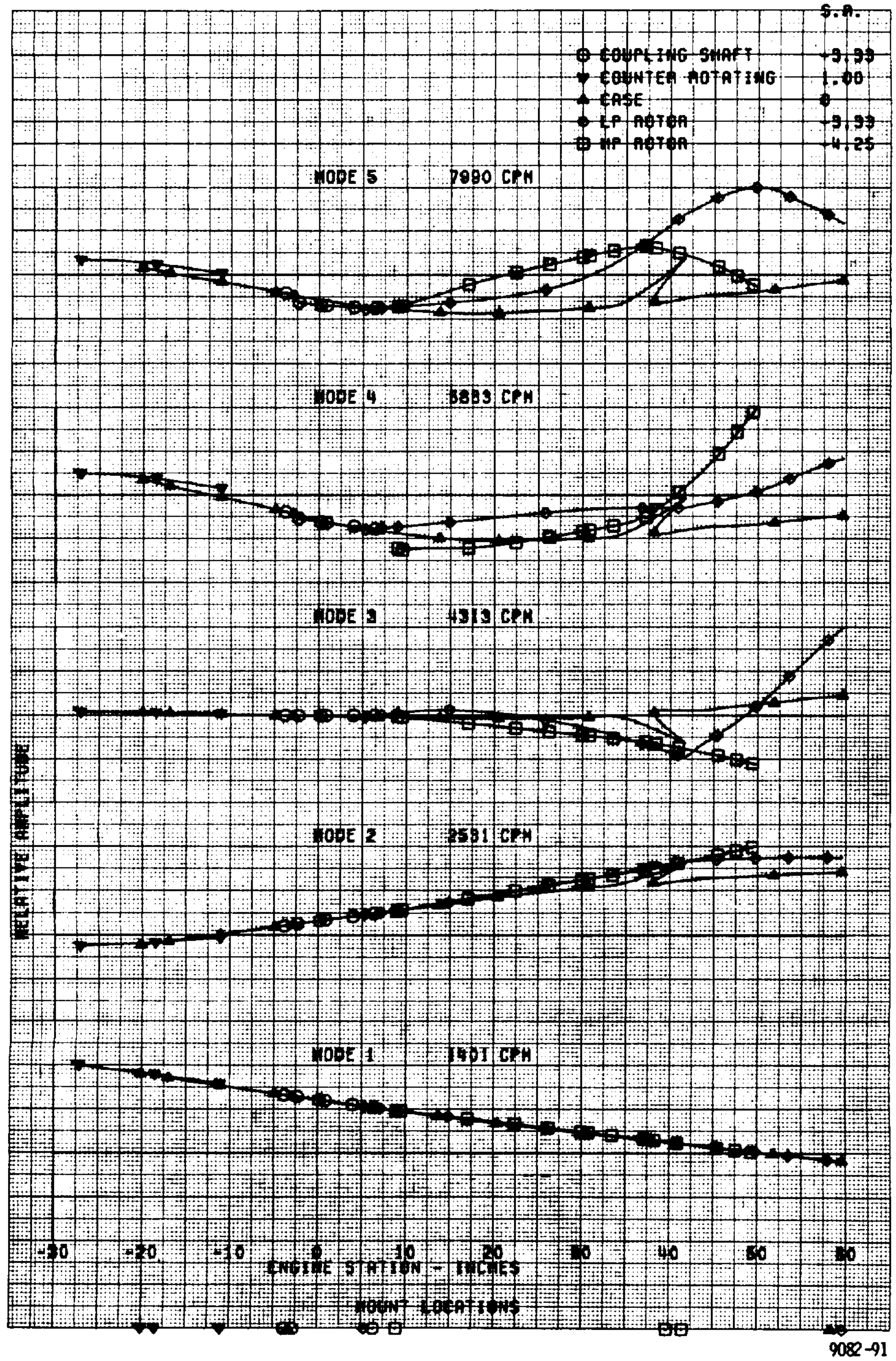


Figure 87. Fan system critical speeds, modes 1-5.

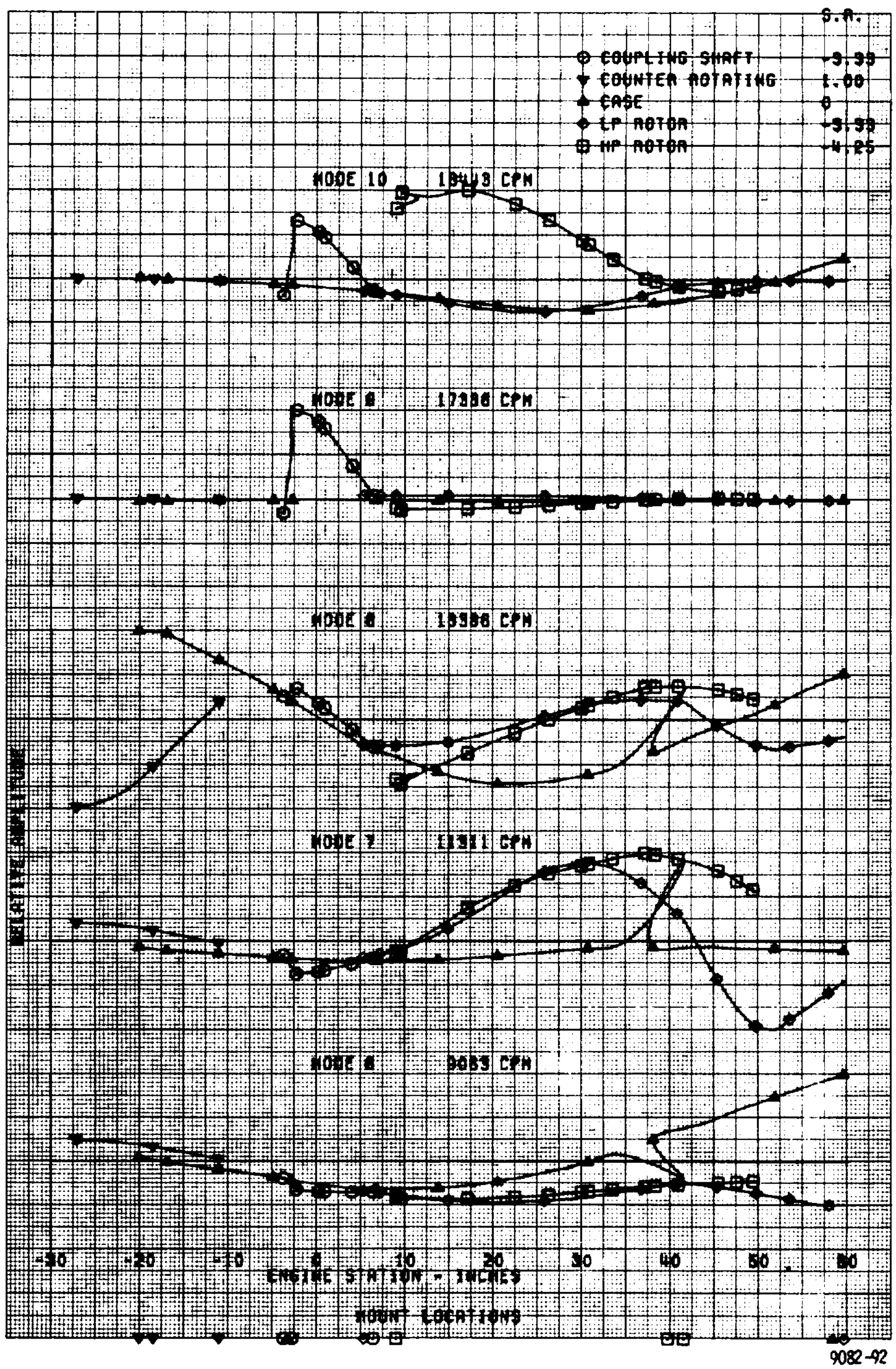


Figure 88. Fan system critical speeds, modes 6-10.

The loads are in the same direction as those of the XT701 and magnitudes are considered equivalent.

The sump pressures of 42.4, 48.4, and 35.0 psia for the front, center, and rear sumps, respectively, are acceptable levels for the vent system.

MODIFICATIONS FOR LIFT/CRUISE ENGINE TILT NACELLE

The modifications required for the tilt-nacelle PD370-25 engine are the same as the ones described for the fixed-nacelle engine except in the area of internal engine oil scavenging.

Figure 78 shows the XT701 internal oil sumps as they would be modified for a tilt nacelle application. Briefly, these changes are summarized as follows:

1. Front sump—addition of positive seal and modified scavenge pickup
2. Center sump—addition of positive seal
3. Rear sump—modified shape to permit vertical scavenging

MODIFICATION FOR CENTER ENGINE

The center engine for both types of V/STOL airframes—tilt and fixed—would be used mechanically unmodified except for the control system. However, in an aircraft with tilt engines, the center engine would also have a modified internal oil system as described under the preceding heading. This allows for interchangeability of the power sections.

TURBINE LIFE

A study has been made to determine the life of the turbine section when operated for 500 hours of the duty cycle shown in Figure 7. The 100% power rating in this cycle occurs at a BOT of 2350°F for 6 minutes or 10% of the total cycle time of 60 minutes. Thus, the RTA will have 50 hours of 100% power during the 500-hour mission. To determine the equivalent hours of life at this maximum temperature, the following assumptions were made:

- 95% thrust BOT = 2272°F (15% of total cycle time)
- BOT levels below 90% thrust have a negligible effect upon blade life
- Between 2272°F and 2350°F, the life expectancy relationship is approximately 3.0:1

The required 500 hours of duty cycle operation are equivalent to 75 hours of continuous operation at the maximum rating of 100% thrust, with a BOT of 2350°F. This is the criterion against which the turbine airfoils were judged for acceptable life. The airfoil lives are summarized in Table XLIV.

TABLE XLIV. TURBINE AIRFOIL MAXIMUM SURFACE TEMPERATURE AND LIFE AT INTERMEDIATE POWER		
Airfoil	Surface temperature (°F)	Stress rupture life (hr)
1V	2054	---
1B	1802	138
2V	1858	---
2B	1846	84
3V	Not critical	---
3B	Not critical	410
4V	Not critical	---
4B	Not critical	285

These data show that the most critical blade is the second stage with a stress rupture life of 84 hours. The most critical vane is the first stage. Both of these airfoils meet the life criteria for the RTA duty cycle. However, the vane surface temperature is somewhat higher than it should be to meet the 75-hour equivalent life without surface oxidation at the vane leading edge. Consequently, surface oxidation may be present on a few vanes that are subjected to the maximum circumferential hot spot. This limited condition is considered to be completely acceptable in a research aircraft engine.

Because the most critical blade has a life expectancy that is 9 hours in excess of the equivalent turbine life, the total number of hours that the RTA can operate to the duty cycle can be calculated. Using the previous assumptions, mission life is calculated to be 560 hours before the total life of the second-stage blade is used.

WATER-ALCOHOL INJECTION OPTION

The RTA 3-engine, 3-fan propulsion system does not include a water-alcohol injection system. However, such a system can be added to the turbofan and turboshaft engines as an option. The water-alcohol system would provide additional power and thrust to the propulsion system when one engine becomes inoperable in the VTOL flight modes.

Effects on Propulsion System Performance

The RTA propulsion system computer card deck can be used to calculate OEI performance with a preset amount of water-alcohol augmentation. On a standard day, the total net thrust of a dry, uninstalled system is calculated to be 29,523 lb. when water-alcohol is injected into the remaining turbofan and turboshaft engines, the total net thrust increases to 31,068 lb—an increase of 5.2%. On a 90°F day, the total net thrust of a dry, uninstalled system is 27,102 lb. With water-alcohol injection, the total net thrust is 29,889 lb—an increase of 10.3%.

Addition of Water-Alcohol System to the Propulsion System

The addition of a water-alcohol system to the lift/cruise turbofan and the XT701-AD-700 turboshaft engine requires minor modifications to the fan frame at the compressor inlet and inlet housing plus the addition of the required plumbing, valves, pumps, tank, etc, as described in the following paragraphs. The components added to each engine weigh 10 lb.

Water-Alcohol Mixture

A 33% methanol, 67% distilled water mixture by volume is used.

General Arrangement of the System

Figure 89 shows the general arrangement of the water-alcohol system for a three-engine V/STOL configuration. Figure 90 shows the injection components installed in the turboshaft engine. Figure 91 shows the nozzles installed in the fan frame at the inlet of the turbofan compressor.

Tables XLV and XLVI are summaries of the water-alcohol flow capacity and weight breakdown, respectively.

Components

The engine-furnished system consists of an aircraft-mounted flow regulator and 10 injector nozzles. The regulator control valve solenoid is energized to open the regulator valve. The regulator controls the flow at 10.6 gal/min per engine. The 10 nozzles are mounted on the inlet housing in the front of the HP compressor inlet. Each nozzle has a plug in the center which produces a widely diffused spray. An inlet screen incorporated in each nozzle protects the nozzle from contamination.

The fuselage-mounted tank has a usable capacity of 32 to 39 gallons. This results in a flow duration of more than one minute, sufficient for one hot day takeoff or an emergency landing.

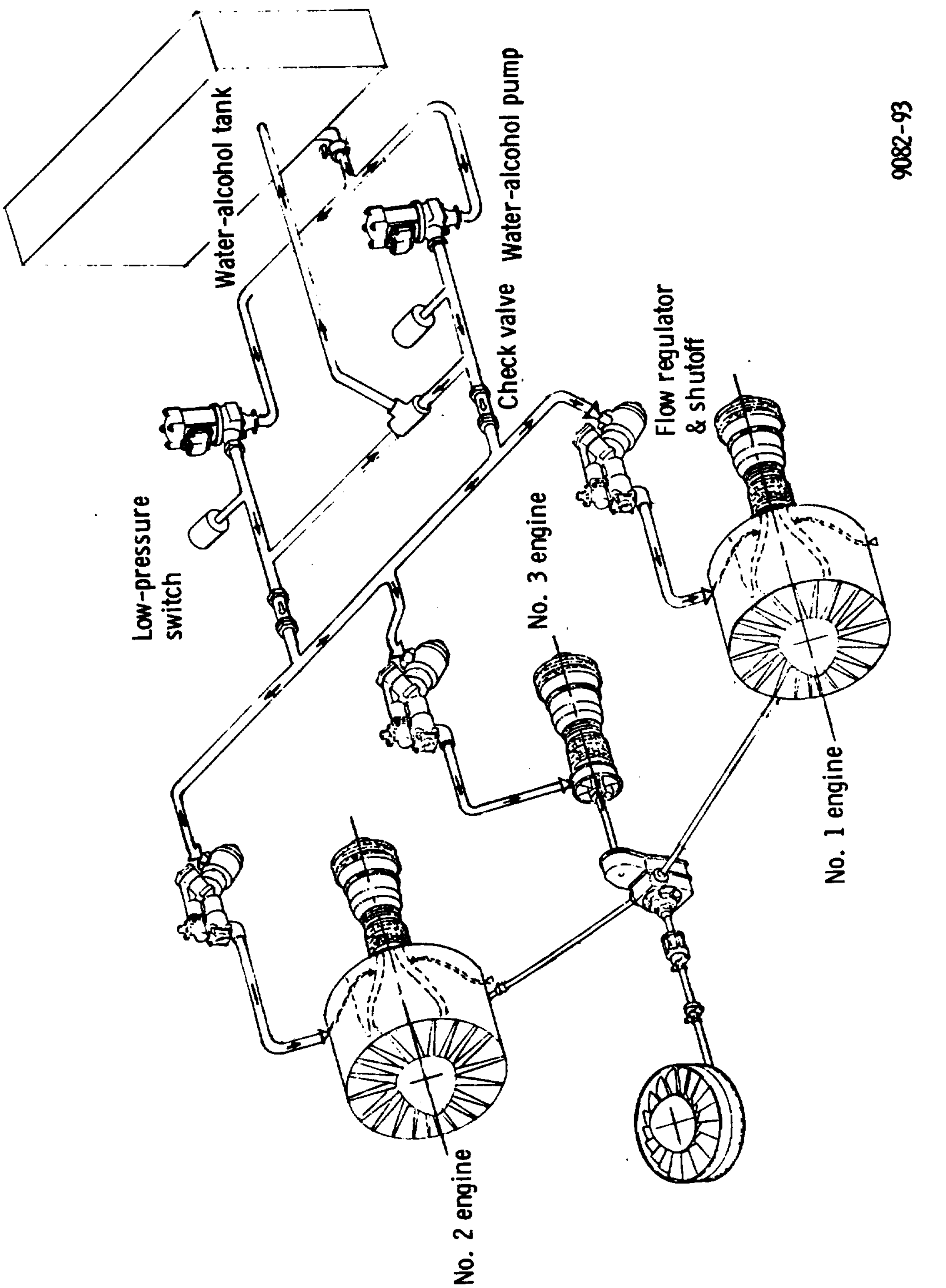


Figure 89. Water-alcohol system schematic.

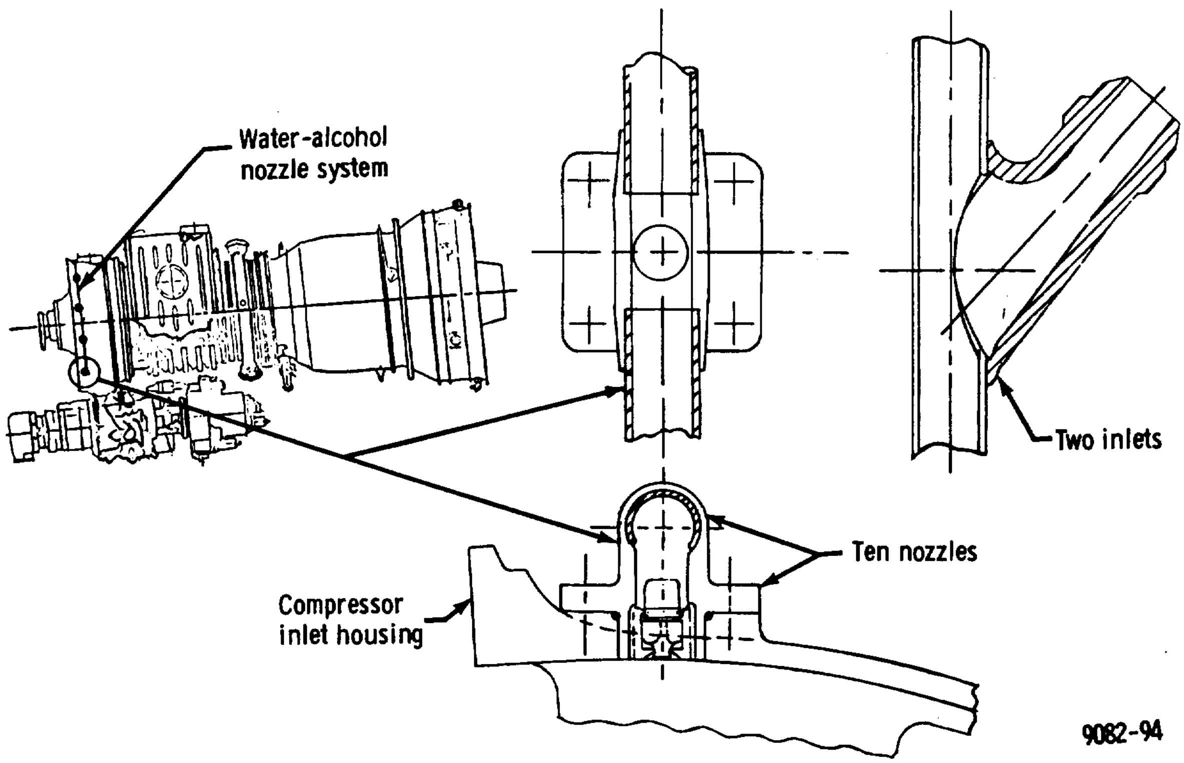


Figure 90. Compressor inlet with water-alcohol modifications.

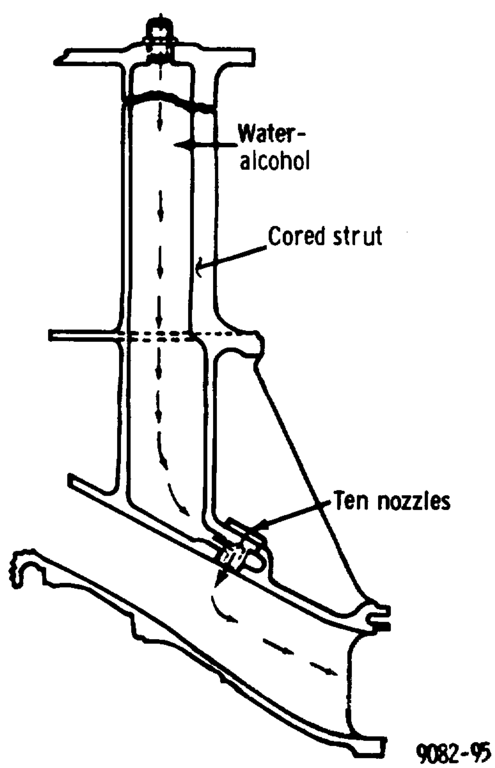


Figure 91. Turbofan inlet with water-alcohol modifications.

TABLE XLV. RTA WATER-ALCOHOL FLOW CAPACITY

	T56-A-10W	RTA V/STOL
Water-alcohol mixture ratio, %		
Methanol	33	33
Water	67	67
Engine requirement		
Number of engines	4	3
Required engine flow, l/s (gal/min)	0.5 (8)	0.7 (10.6)
Total required flow, l/s (gal/min)	2 (32)	2 (31.8)
Motor-driven pump		
Number used	2	2
Single pump capacity at 1034 kPa, l/s (150 psi, gal/min)	2 (32)	2 (32)
Flow regulator and shutoff (DDA supplied)		
Required flow, l/s (gal/min)	0.5 (8)	0.7 (10.6*)

* Note: T56 flow regulator will be modified internally to provide required regulated flow output.

TABLE XLVI. AIRCRAFT WATER-ALCOHOL SYSTEM WEIGHT BREAKDOWN

Quantity	Item	Weight (lb)
2	Water-alcohol pumps	25
2	Pressure switches	2
2	Check valves	2
3	Regulators and shutoff	21
30	Nozzles	9
	Tank, wiring, piping, and mounts	96

Note: An interface definition would be established between airframer and DDA on supply of W-A system components. Therefore, the components listed, except for regulators and nozzles, have not been included in engine weight additions.

The centrifugal pumps are motor driven; each has a capacity of 32 gal/min. One pump is capable of supplying the required volume of flow. Two pumps mounted in parallel are desirable for reliability. The pump outlets are connected to a distribution manifold which delivers water-alcohol to each engine.

PROPULSION SYSTEM SAFETY

PROPULSION SYSTEM HAZARD ANALYSIS

Propulsion system hazards, as applicable to MIL-STD-882, paragraph 5.8.2.1, excepting q, were evaluated during the preliminary design. A fault tree method of analysis of propulsion system components was used to identify real or potential undesirable events that could, without control to preclude occurrence, result in a Category IV safety hazard. These events comprise the following:

- Noncontainment of high-energy pieces
- Fire external to the engine
- Loss of fan rotation
- Loss of engine/nacelle
- Toxic fumes
- Torsional instability
- Simultaneous multiple-engine shutdown

An assessment of the 78 components and conditions that could contribute to the preceding real or potential undesirable events revealed that adequate preliminary design considerations have been applied toward precluding failure in five of the seven events.

Torsional instability and simultaneous multiple-engine shutdown would require particular attention in a final design to preclude those occurrences. These events are related to the complete propulsion system and are not a part of the current preliminary design effort.

Preliminary hazard analysis recommendations for the final design and testing of the system and components are presented herein and are grouped under the appropriate event.

- Noncontainment of High-Energy Pieces
  - Evaluate compressor blade frequencies against passage frequencies generated with the addition of the fan stage.
  - Evaluate compressor bladings for potentially excessive stresses under distorted compressor inlet conditions accompanying the tilt mode.
  - Final-design fan blade natural frequencies, mode shapes, stress distribution, and fatigue life should be determined in bench vibratory tests. Operating stresses should be determined during engine testing with strain gage instrumentation.
  - Finite element analysis should be a part of the fan wheel final design evaluation and areas of maximum stress should be evaluated during engine testing.

- The self-lubricating approach to blade angle variation and retention should be evaluated early in bench and/or whirl rig testing for assurance that the bearing/wheel raceway interface does not affect the reliability of the wheel.
- The containment capability of the final-design fan casing should be verified using final-design blade energies.

- Fire External to Engine
  - Survey the vibratory response of the relocated, reoriented fuel control in the lift/cruise configuration.

- Loss of Fan Rotation
  - Conduct a finite element analysis of the final-design fan shaft.

- Loss of Engine Nacelle
  - A thorough structural analysis plus load test verification of the fan casing should be conducted in the event the tilt nacelle concept is used.
  - A static load test of the lift/cruise fan engine carcass should be conducted with airframer-responsible engine/nacelle mounting included.
  - The lift/cruise engine inlet housing design should be verified in the same manner as the XT701 hardware.

- Toxic Fumes
  - None

- Torsional Instability
  - A computer simulation of the aircraft propulsion system dynamic characteristics should be made.
  - A Failure Mode and Effect Analysis (FMEA) propulsion control system should be conducted. This analysis would evaluate control system modifications for lift/cruise engine adaptation and the integration of the fan variable-pitch control into the propulsion system control.

- Simultaneous Multiple Engine Shutdown
  - Perform an FMEA of the electronic control for potential failure modes that cause engine shutdown.
  - Use a dynamics program to analyze the effect of fan blade unloading on potential engine overspeed.
  - The FMEA of the propulsion control system should also evaluate a potential shutdown triggering failure.
  - Two power turbine speed sensors from the XT701 design should be retained for redundancy against a lost or undetected speed sense.

All recommendations are items normally considered in a final design and would be evaluated in the final design of an RTA propulsion system.

LIFT FAN ASSEMBLY HAZARD ANALYSIS

An FMEA and a Preliminary Hazard Analysis was conducted for the V/STOL aircraft lift fan assembly based on Hamilton Standard drawing SK 92923 (Figure 92).

The Category IV failures noted in the FMEA were extracted and compiled into the Preliminary Hazard Analysis, which tabulates the hazards by incident. Three hazardous consequences were found:

1. Inability to change pitch
2. Loss of lift fan function
3. Aircraft damage

The following are the possible incidents of each hazardous consequence:

- Inability to Change Pitch
  - Seizure of actuator
  - Seizure or binding of center rod
  - Galling or seizure of blade retention bearings
  - Fracture of actuator structure (cylinder)

- Loss of Lift Fan Function
  - Seizure of gearbox bearing
  - Seizure of input shaft bearings
  - Fracture of pinion gear
  - Fracture of the input drive flange and shaft
  - Retaining nut 75 loosens or threads fail
  - Retaining nut 76 loosens or threads fail
  - Retaining nut 78 loosens or threads fail
  - Locking nut 82 loosesn or threads fail
  - Locking nut 84 loosens or threads fail
  - Fracture of gearbox structure

- Aircraft Damage
  - Fatigue fracture of blade spar
  - Fracture of blade retention structure

Potential Category IV failures have been referred back through the design process to provide additional safety protection by redesign or by increasing the component design safety margin.

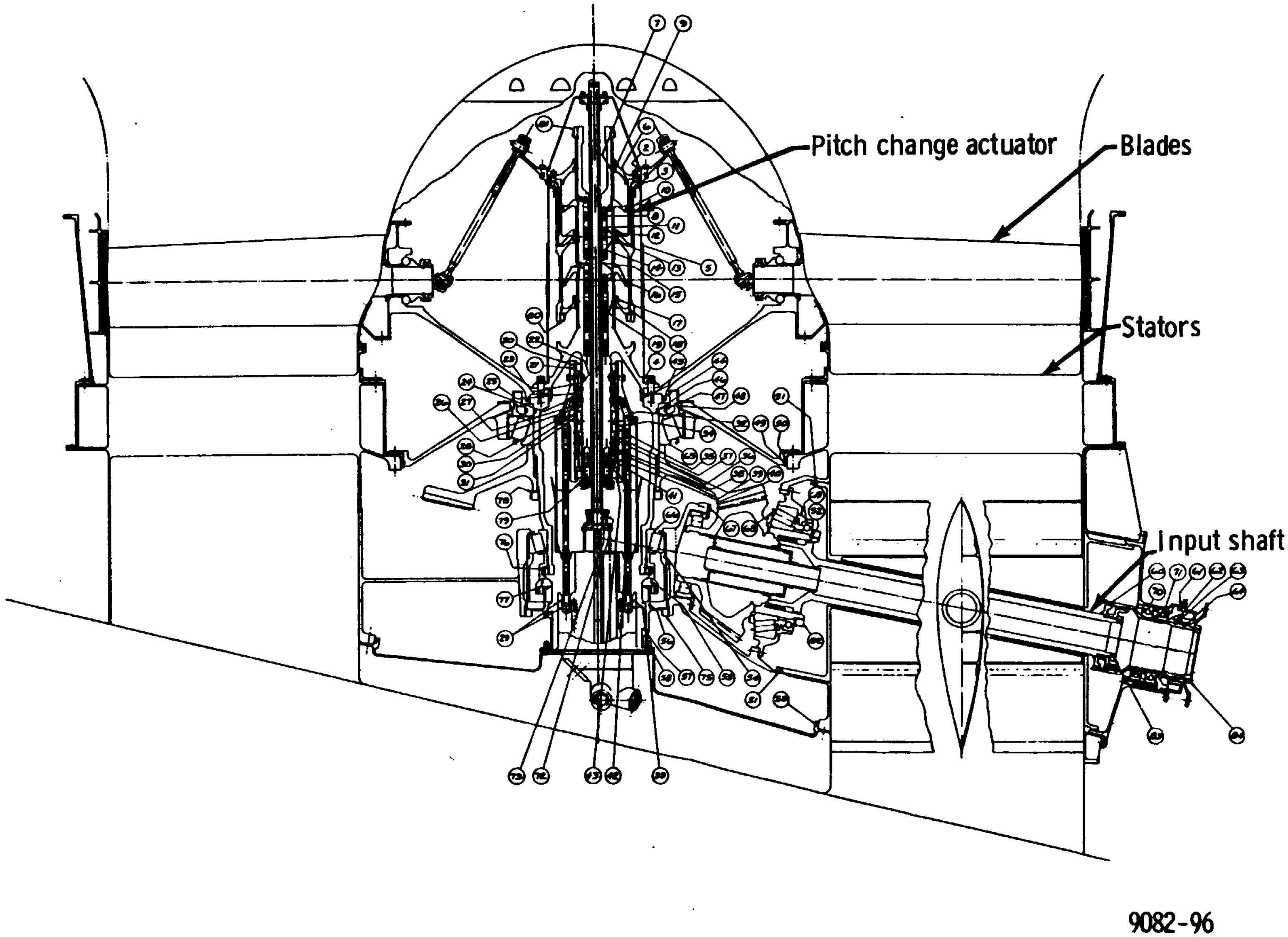


Figure 92. Lift fan assembly.

CONCLUSIONS

The V/STOL Research and Technology Aircraft propulsion system consists of two lift/cruise, variable-pitch turbofan engines, one turboshaft engine, and one variable-pitch lift fan—all connected with shafting through a combiner gearbox. Design effort was limited to components of the lift/cruise engines, turboshaft engine modifications, lift fan assembly, and propulsion system performance generation.

The following conclusions have been derived from the design:

1. The PD370-30 and PD370-32 propulsion systems provide the modified T39-based Research and Technology Aircraft with sufficient VTOL and cruise thrust levels.

2. Detail design and manufacturing of lift/cruise turbofan engines and lift fan components can be completed with current technology.

3. The use of existing engines and gearing will reduce propulsion system development time and costs.

4. Lift and lift/cruise fan rotor interchangeability will reduce development time and costs.

5. Lift/cruise gearbox components and lift fan gearbox components have different requirements and are therefore not interchangeable.

APPENDIX A

CONVERSION TABLE

To convert from	To SI units	Multiply by
	Acceleration	
foot/second^2	metre/second^2	0.3048
	Area	
inch^2	metre^2	0.00064516
	Energy, Work, Heat	
British thermal unit	joule	1055.056
foot-pound-force	joule	1.355818
	Flow Rate, Mass/Time	
gallon/minute	litre/second	0.06309
pound-mass/second	kilogram/second	0.4535924
pound-mass/hour	kilogram/second	0.000126
pound-mass/hour (fuel flow)	gram/sec	0.125998
pound-mass/hour (fuel flow)	kilogram/hour	0.4535924
	Force	
pound-force	newton	4.448222
	Specific Fuel Consumption	
pound-mass/pound-force-hour	milligram/newton-second	28.32545
	Length, Distance	
foot	metre	0.3048
inch	millimetre	25.4
	Mass	
pound-mass	kilogram	0.4535924

To convert from	To SI units	Multiply by
	Moment, Torque	
pound-force-inch	newton-metre	0.1129848
pound-force-foot	newton-metre	1.355818
	Power	
horsepower	kilowatt	0.7457
	Pressure of Stress, Force/Area	
pound-force/foot^2	kilopascal	0.04788
pound-force/inch^2 (pressure)	kilopascal	6.894757
pound-force/inch^2 (stress)	megapascal	0.006895
	Temperature	
degree Fahrenheit	kelvin	$t_K = (t_F + 459.67)/1.8$
degree Rankine	kelvin	$t_K = t_R/1.8$
	Velocity	
foot/minute	metre/second	0.00508
foot/second	metre/second	0.3048
knot	metre/second	0.514444
	Volume	
foot^3	metre^3	0.028317
gallon	metre^3	0.003785
gallon	litre	3.7854
inch^3	metre^3	1.6387×10^{-5}

APPENDIX B

LIST OF SYMBOLS

Symbol	Definition	Units
A	Fan inlet area	ft^2
AEO	All engines operation	---
Al	Aluminum	---
BMAD	Boeing Military Aircraft Division	---
BPR	Bypass ratio	---
Btu	British thermal units	---
CCW	Counterclockwise	---
CG	Center of gravity	---
C_M	Meridional velocity	ft/sec
CPM	Cycles per minute	---
CSD	Constant speed drive	---
CW	Clockwise	---
$\overline{C_X}$	Mass flow averaged axial velocity	ft/sec
C355-T61	Cast aluminum alloy	---
D	Diffusion factor	---
DCA	Double circular arc	---
DDA	Detroit Diesel Allison	---
DN	Relative speed (Bearing bore X shaft speed)	mm-rpm
DP	Diametral pitch	---
d	Streamline diameter	inches
d_1	Streamline diameter rotor inlet	inches
d_2	Streamline diameter rotor exit	inches
EOF	Inoperative core engine fan	---
FGT	Unit total gross thrust	pounds
FMEA	Failure Mode and Effect Analysis	---
FNP	Net thrust from primary nozzle	pounds
FNS	Net thrust from secondary nozzle	pounds
FNT	Unit total net thrust	pounds
FOD	Foreign object damage	---
FPR	Fan pressure ratio	---
F/C	Fuel control	---
F/P	Fuel pump	---
ft	Feet	---
g	Acceleration of gravity	ft/sec^2
gal/min	Gallons per minute	---

Symbol	Definition	Units
HP	High pressure	---
HS	Hamilton Standard	---
hp	Horsepower	---
i	Incidence	Degrees
IGV	Inlet guide vane	---
K_R	Radial distortion index	---
ksi	Thousands of pounds per square inch	---
$K\theta$	Circumferential distortion index	---
LF	Lift fan	---
LP	Low pressure	---
LVDT	Linear variable differential transformer	---
L/C	Lift/cruise	---
lb	Pound	---
M	Relative Mach number	---
Mach	Flight Mach number	---
McAIR	McDonnell Aircraft Company	---
MS	Military Specification	---
MTBF	Mean time between failure	---
M_A	Relative Mach number	---
M_M	Meridional Mach number	---
M_N	Mach number	---
mm	Millimeter	---
N	Number of gear teeth	---
NCOR	Fan corrected speed or turboshaft HP compressor corrected speed	%
$N/\sqrt{\theta}$	Corrected rotational speed	rpm
OD	Outside diameter	inches
OEI	One engine inoperative	---
OGV	Outlet guide vane	---
P	Stagnation pressure	psia
PITCH	Fan blade pitch angle referenced to nominal setting	degree
PLV	Pitch line velocity	ft/sec
PMG	Permanent magnet generator	---
PSI or psi	Pounds per square inch	---
PTP	Absolute total pressure into primary nozzle	psia
PTS	Absolute total pressure into secondary nozzle	psia
P_R	Stagnation pressure ratio	---
P_T/P_T	Inlet pressure recovery	---

Symbol	Definition	Units
QAD	Quick attach and detach	---
RPM or rpm	Revolutions per minute	---
RTA	Research and Technology aircraft	---
SFC	Specific fuel consumption	lb/hr/lb
SHP or shp	Shaft horsepower	---
SL	Streamline	---
SR	Speed ratio	---
s	Second	---
T	Stagnation temperature	°R
TF	Turbofan unit	---
TFH	Turbofan unit with input power for attitude control	---
TFL	Turbofan unit with power extraction for attitude control	---
TS	Turboshaft unit	---
TTP	Total temperature into primary nozzle	°R
TTS	Total temperature into secondary nozzle	°R
T56-A-14	Allison turboshaft engine	---
T56-A-18	Allison turboshaft engine	---
t/b	Blade thickness ratio	---
V	Vanadium	---
VHN	Vickers hardness number	---
VP	Variable pitch	---
V/STOL	Vertical or short takeoff and landing	---
VTO	Vertical takeoff	---
VTOL	Vertical takeoff and landing	---
WCOR	Corrected inlet airflow	lb/sec
W_F	Unit fuel flow	lb/hr
WP	Gas flow into primary nozzle	lb/sec
WS	Airflow into secondary nozzle	lb/sec
$W\sqrt{\theta}/\delta A$	Corrected flow per square foot of rotor inlet annulus area	$lb/ft^2/sec$
Z	Loss coefficient	---
1E-1F	One engine and one fan	---
2E-3F	Two engines and three fans	---
3E-3F	Three engines and three fans	---
α	Absolute air angle	degrees
α_1*	Stator inlet metal angle	degrees
α_2*	Stator exit metal angle	degrees
β	Rotor pitch angle	degrees
β_{REF}	Design rotor pitch angle	degrees

Symbol	Definition	Units
β	Relative air angle, ref to meridional direction	degrees
$\beta_1{}^*$	Rotor inlet metal angle	degrees
$\beta_2{}^*$	Rotor exit metal angle	degrees
$\Delta\beta$	Change in rotor pitch angle from design blade angle	degrees
δ	Deviation angle	degrees
δ	$P_{amb}/29.92$	inches of mercury
η_{AD}	Adiabatic efficiency	---
ψ	Duct angle of attack	degrees
ϕ	$\tan^{-1}$ of streamline slope	---
θ	$T_{amb}/519°R$	---
τ/b	Gap-to-chord ratio	---